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Geology of the Kuzumaki–Kamaishi Subbelt of the North Kitakami Belt (a Jurassic accretionary complex), Northeast Japan: Case study of the Kawai–Yamada area, eastern Iwate Prefecture

NORITOSHI SUZUKI[1], MASAYUKI EHIRO[2], KEN YOSHIHARA[1], YUKI KIMURA[1], GOICHI KAWASHIMA[1], HIDEAKI YOSHIMOTO[1] and TAISHI NOGI[1]

[1]*Institute of Geology and Paleontology, Graduate School of Science, Tohoku University, Sendai 980–8578, Japan*

[2]*The Tohoku University Museum, Sendai 980–8578, Japan*

Abstract. **The Kuzumaki–Kamaishi Subbelt, a Jurassic accretionary orogen, is a western subdivision of the NNW–trending North Kitakami Belt in the Northern Kitakami Massif, Northeastern Japan. This subbelt is found in eastern central Iwate Prefecture, including the Toyomane–Kazawa area; in the southeastern, southwestern, and northwestern areas of Moichi City; and in the Kawai area. We mapped the accretionary complexes of the Kuzumaki–Kamaishi Subbelt in these areas and newly divided them into the following six complexes, bounded by faults and arranged from east to west: the Moichi, Tanesashi, Kitakawame, Tsugaruishi, Karomori, and Takatakimori Complexes. These complexes were further subdivided into the Kariya Subcomplex of the Moichi Complex; the Nagasawarokkumi, Minamikawame, Komatsugura, and Sambotoji Subcomplexes of the Tanesashi Complex; the Warabinosawa and Nagaiwamori Subcomplexes of the Kitakawame Complex; the Taguri, Sippyou, Okudaira, Fukushi, and Furuyadomori Subcomplexes of the Tsugaruishi Complex; the Kotanichi, Choukomori, Shiraitotaki, and Yasomori Subcomplexes of the Karomori Complex; and the Kirinai and Komataguchi Subcomplexes of the Takatakimori Complex. The Warabinosawa and Horochi faults bound the western and eastern sides of the Kitakawame Complex, respectively. The Kirinai and the Hayachine Eastern Marginal faults also separate the Takatakimori Complex from the Tsugaruishi and Karomori Complexes to the east–northeast and from the northern marginal part of the South Kitakami Belt to the west–southwest, respectively.**

At a mappable scale, the major parts of the Tsugaruishi and Tanesashi Complexes usually dip shallowly to the SSW. Like the underlying Tsugaruishi Complex, the Karomori Complex also tilts shallowly. In contrast, bedding planes on visible outcrop structures dip subvertically to vertically. This difference can be explained by intrafolial folding prior to the development of the faulted boundaries between the subcomplexes.

The North Kitakami Belt has the following tectonic framework: (1) The Kuzumaki–Kamaishi Subbelt is comprised of Carboniferous to Middle Permian fusulinid–bearing limestones, Lower Permian to probable Jurassic chert, Upper Olenekian siliceous mudstone, Middle to Late Jurassic siliceous mudstone and mudstone, greenstone of unknown age, sandstone of probable Middle–Late Jurassic age, and a minor amount of Jurassic or older coral–bearing limestones. (2) The Akka–Tanohata Subbelt contains Upper Olenekian siliceous mudstone, Upper Olenekian to probable Jurassic chert, Middle Jurassic to the lowest Cretaceous mudstone and siliceous mudstone, Triassic limestone overlying within–plate basalts, Jurassic macrofossil–bearing limestone, and siliciclastic rocks of probable Middle Jurassic to earliest Cretaceous age. Although the Kuzumaki–Kamaishi Subbelt has not yet been correlated exactly to the Southern Chichibu Belt of southwest Japan because of a lack of same–age lithostratigraphic relationships, the Kuzumaki–Kamaishi Subbelt may be a missing part of the Southern Chichibu Belt.

Key words: Jurassic, accretionary complex, North Kitakami Belt, Iwate, Japan

1. Introduction

The Kuzumaki–Kamaishi Subbelt, the western part of the North Kitakami Belt, is distributed in the Northern Kitakami Massif in the Tohoku region of northern Japan. The subbelt is occupied by the Jurassic accretionary complexes that comprise a major part of the basement rocks in Japan (Minoura, 1983, 1985; Minoura and Tsushima, 1984; Oho and Iwamatsu, 1986) and consist of pelagic sequences, fragments of greenstones such as seamounts, and trench-fill deposits. The North Kitakami Belt initially formed as part of a single, long accretionary complex belt along the eastern margin of the East Asian continent. That Jurassic accretionary complex has since separated into the Taukha Belt of Far East Russia, the North Kitakami Belt, the Southern Chichibu Belt of Southwestern Japan, and the Busuanga Belt of the Philippines (e.g. Yamakita and Otoh, 2000a). Separation has been caused by tectonic events such as north-trending sinistral faulting along the eastern margin of continental Asia in Cretaceous-Paleogene time and the opening of the back-arc basin in the Sea of Japan in the Cenozoic (e.g. Yamakita and Otoh, 2000a). To reconstruct the tectonic history along continental East Asia in the Mesozoic, precise tectonostratigraphic correlation among these belts using lithostratigraphic, biostratigraphic, and tectonostratigraphic data is essential. However, less information has been available on the North Kitakami Belt compared to the Southern Chichibu Belt. Fewer geological maps have been made of the area, and high thermal metamorphisms caused by Early Cretaceous plutonic activ-

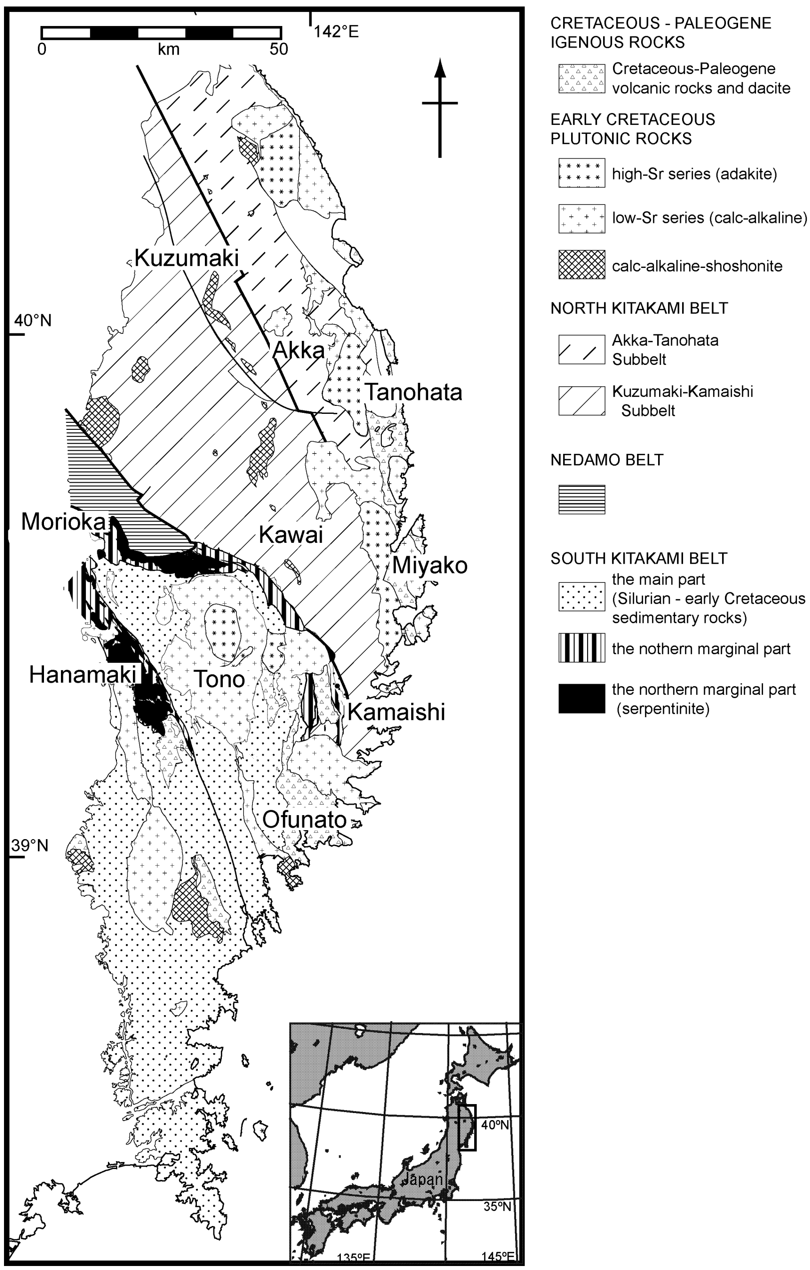


Figure 1. Schematic tectonic division for the Paleozoic-earliest Cretaceous rocks in the Kitakami Massif, northeast Japan (Modified from Ehiro and Suzuki, 2003. Tectonic divisions are based on Ehiro *et al.*, 2005).

ities (e.g., Moriya, 1972) have made a determination of the depositional age difficult. Correlation of tectonostratigraphic complexes between the Kuzumaki-Kamaishi Subbelt and other relevant belts has been particularly difficult because no significant key lithology has been found in this subbelt.

Since initial reports on the geology of the North Kitakami Belt in the 1910s (Nakamura, 1911 ; Obinata, 1912 ; Yamane, 1915), several geologic maps of the Kuzumaki-Kamaishi Subbelt have been published. However, the maps contain contradictions, primarily about whether the belt has a vertical structure (Iwate Prefecture, 1954 ; Moriya, 1972 ; Murai *et al.*, 1985, 1986 ; Onuki, 1981 ; Osawa, 1983 ; Yoshida, 1980 ; Yoshida, 1961 ; Yoshida and Takada, 1964) or a shallowly westward-titling structure (Okami, 1990 ; Okami *et al.*, 1993). The tectonostratigraphic implications of these differences remain unclear, but additional information has been gathered on the origin of Permian limestone blocks (Tazawa *et al.*, 1997), the presence of Mesozoic scleractinian corals (Ehiro *et al.*, 2001), and the paleoceanographic position of the sedimentary rocks of the Kuzumaki-Kamaishi Subbelt in the early Jurassic (Suzuki and Ogane, 2004). Before relevant belts can be correlated, detailed field maps based on paleontologic, petrologic, and structural geologic data are needed.

This paper describes the precise lithostratigraphic distribution of the Jurassic accretionary complexes of the Kuzumaki-Kamaishi Subbelt in the Kawai, Moichi, and Toyomane-Kazawa areas in eastern Iwate Prefecture, an appropriate location for examining subbelt transections. This paper also describes the petrology and fossil occurrence of clastic rocks, greenstones, and mesoscopic and macroscopic geologic structures, and discusses the origin of the rocks, the formation of the geologic structures, possible correlation to the Southern Chichibu Belt, and the geologic history of the Kuzumaki-Kamaishi Subbelt. One purpose of this paper is to provide detailed and easily accessible field data for use in future studies.

2. Historical review of the tectonic division of the Northern Kitakami Massif

The tectonic divisions of the Northern Kitakami Massif have been revised numerous times. Thus, to clarify the current categorization, we first review the tectonostratigraphic framework that was given previously for the Kitakami Massif. For instance, the study area has been called "the Kuzumaki-Kamaishi Belt (or Subbelt)," "part of the Kuribayashi Formation," "the Northern Kitakami Terrane," and "the Kamaishi Formation," based on different definitions. The same name has also been based on different definitions, as in the "North Kitakami Belt" in reports by Yoshida (1968) and Ehiro *et al.* (2005).

Pre-Tertiary rocks of the Kitakami Mountains are now divided into three tectonostratigraphic belts (Fig. 1) : the North Kitakami, Nedamo, and South Kitakami belts, from northeast to southwest (Ehiro and Suzuki, 2003 ; Ehiro *et al.*, 2005 ; Otoh and Sasaki, 2003). The North Kitakami Belt is subdivided into the Akka-Tanohata and Kuzumaki-Kamaishi subbelts. These subbelts are bounded by the NNW-trending Seki Fault and differ in their petrographic compositions of sandstone and in the ages of exotic blocks (Okami and Ehiro, 1988). The Kuzumaki-Kamaishi Subbelt is marked by plagioclase- and volcaniclastic-rich sandstone and by the presence of blocks of Carboniferous to Triassic limestone and Permian to Triassic chert. In contrast, the Akka-Tanohata Subbelt is characterized by orthoclase- and quartz-rich sandstone and the presence of blocks of Triassic chert and Triassic to Jurassic limestone.

The geotectonic framework of basement rocks in the Kitakami Mountains was initially proposed by Minato (1950), who recognized lithostratigraphic differences between the Northern and Southern Kitakami Mountains (Fig. 2a). The northern part of the Kitakami Mountains (NPP in Fig. 2a) is dominated by chert and sporadically yields fossils ; this area roughly corresponds to the Kuzumaki-Kamaishi and Akka-Tanohata subbelts in the present scheme. The southern part of the mountains (SPP in Fig. 2a) is typified by coarse-grained clastic rocks, limestone, and abundant fossils. Minato (1950) called the former the "northern Paleozoic province" (English-language terms were used by Owa [1956] ; "the north type Paleozoic System of the Kitakami Mountainland" by Yoshida [1961] ; "the northern rock facies of the Paleozoic of the Kitakami Mountainland" by Yoshida and Katada [1964]) and "the northern type of the Paleozoic strata of the Kitakami Mountainland" and the latter the "southern Paleozoic province" (in English, Yoshida [1961] called this "the southern rock facies of the Paleozoic of the Kitakami Mountainland"). However, Minato (1950) did not provide any detailed geologic maps, and little geologic information was available on the northern Kitakami Mountains at the time of his study, with the exception of reports on the occurrence of Permian-carbonate fossils (Hanzawa, 1954 ; Tamura *et al.*, 1952). A geological map covering the Kitakami Mountains was later published as eight separate 48' quadrangle geologic maps at a scale of 1 : 100,000 ; these maps show chert and schalstein as dominant in the northern Kitakami Mountains (Iwate Prefecture, 1954). Based on the lithologic distributions, Onuki (1956) recognized three provinces in the northern Kitakami Mountains, from southwest to northeast : (1) schalstein-rich (SRP in Fig. 2b), (2) chert-rich (CRP in Fig. 2b), and (3) limestone-, schalstein-, and chert-intercalations-rich (IRP in Fig. 2b) provinces. All of the basement rocks in the northern Kitakami Mountains had been considered Paleozoic, but Hase *et al.* (1956) pointed out the occurrence of Upper Jurassic and Lower Cretaceous fossils from the eastern margin of the northern Kitakami Mountains. Subsequently, Kano (1958) separated this zone from the Paleozoic part of the northern Kitakami Mountains, calling it the Outer Kitakami Belt.

From the mid-1950s to the late 1960s, Owa (1956), Yoshida, T. (1961), and Yoshida and Katada (1964) mapped the geology of broader regions at a scale of 1 : 50,000. Yoshida and Katada (1964) geologically divided the Kitakami Massif into the northern Paleozoic province (NPP in Fig. 2c), Hayachine Tectonic Belt (HTB in Fig. 2c), ultra-mafic rocks (um and mg in Fig. 2c), and the southern Paleozoic province (SPP in Fig. 2c). A number of other reports also provided additional

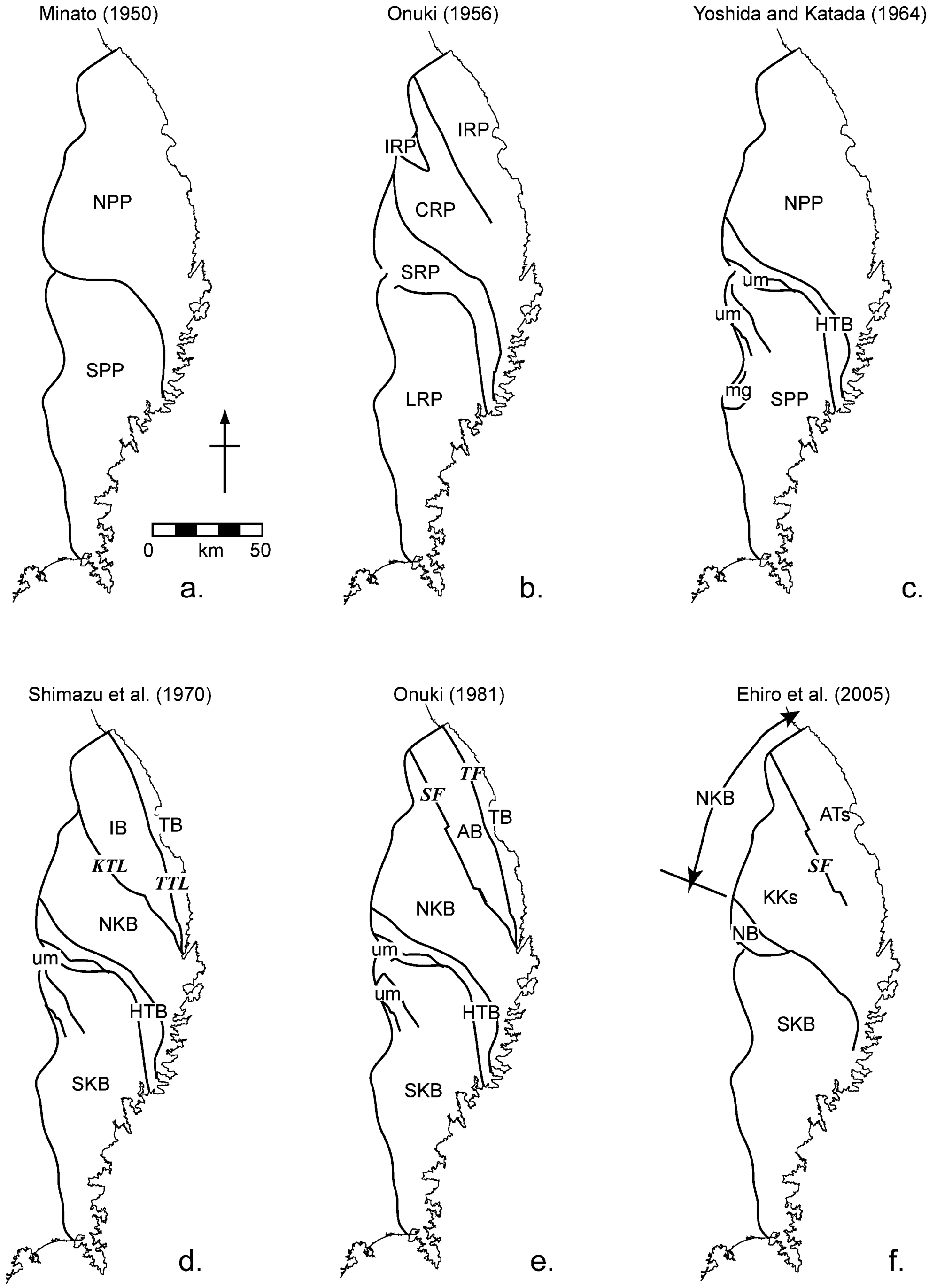


Figure 2. Historic maps of the simplified tectonic division for the Paleozoic–earliest Cretaceous rocks in the Kitakami Massif, northeast Japan. Detailed explanations are provided in the text. (a.) Tectonic division by Minato (1950), (b.) Tectonic division by Yoshida and Katada (1964), (c.) Tectonic division by Onuki (1956), (d.) Tectonic division by Shimazu *et al.* (1970), (e.) Tectonic division by Onuki (1981), (f.) Tectonic division by Ehiro *et al.* (2005).

Abbreviations. AB : Akka Belt, ATs : Akka–Tanohata Subbelt, CRP : chert–rich province, mg : the Motai Group, HTB : Hayachine Tectonic Belt, IB : Iwaizumi Belt, IRP : limestone–, schalstein–, and chert–intercalations–rich province, KKs : Kuzumaki–Kamaishi subbelt, *KTL* : Kuzumaki Tectonic Line, LRP : limestone–rich province, mg : Motai Group, NB : Nedamo Belt, NKB : North Kitakami Belt, NPP : the northern Paleozoic Province, *SF* : Seki Fault, SKB : South Kitakami Belt, SPP : the southern Paleozoic Province, SRP : Schalstein–rich province, TB : Taro Belt, *TF* : Taro Fault, *TTL* : Taro Tectonic Line, um : ultramafic and mafic rocks.

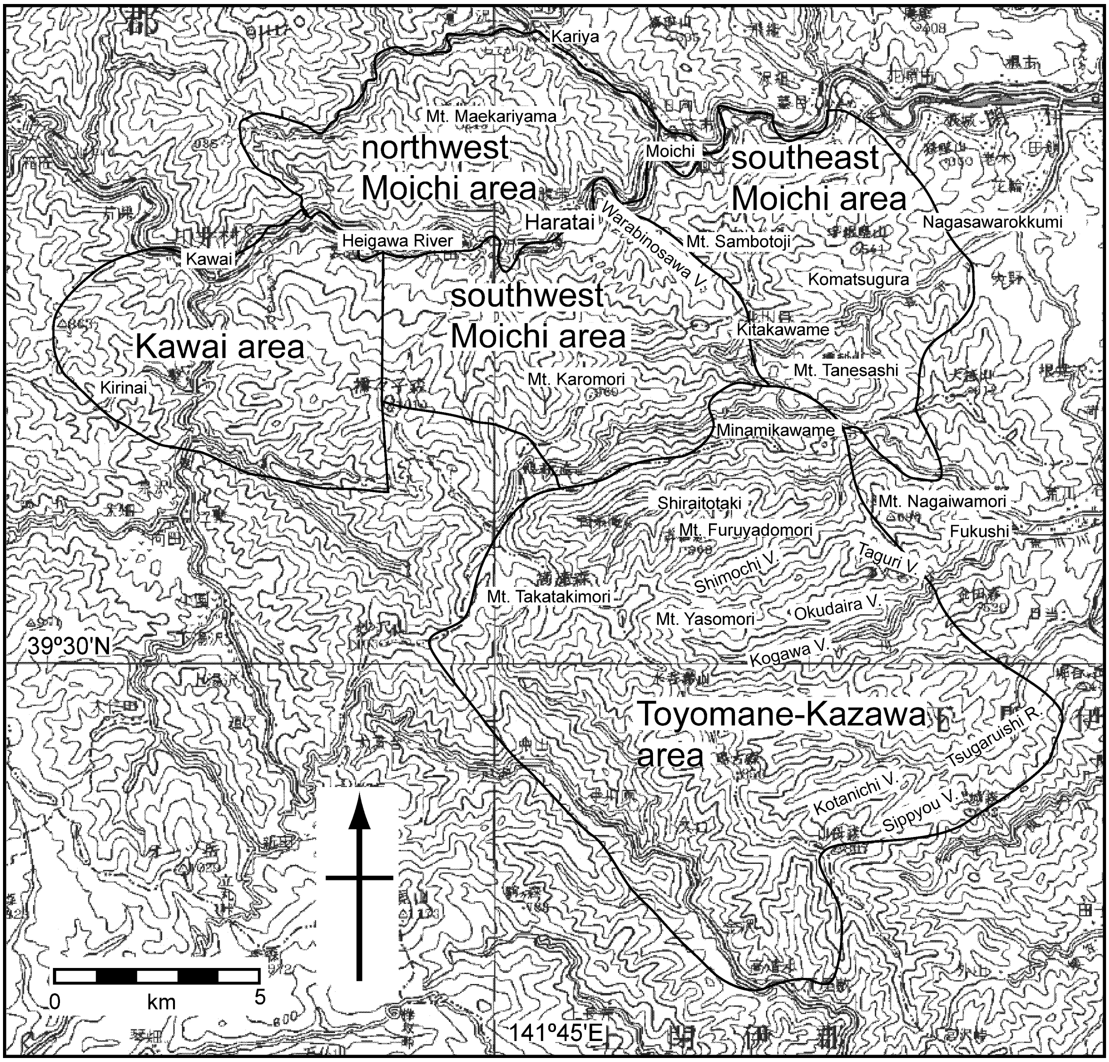


Figure 3. Field mapping areas referred to this paper, indicating the geographic names for the names of the stratigraphic divisions. "Tsugaruishi" is located to the west off this map. The base map is after the 1 : 200,000-scale topographic quadrangle map "Morioka" by the Geographical Survey Institute of Japan.

lithostratigraphic and biostratigraphic information (Moriai and Oikawa, 1969 ; Onuki and Kudo, 1954 ; Onuki *et al.*, 1960 ; Sugimoto, 1969). These cumulative data enabled tectonostratigraphic divisions of the Northern Kitakami Massif, and Yoshida (1968) proposed the following three tectonostratigraphic complexes : the North Kitakami Belt (NKB in Fig. 2d), Iwaizumi Belt (IB in Fig. 2d), and the Taro Belt (TB in Fig. 2d), from southwest to northeast. A paper by Shimazu *et al.* (1970) was the first to illustrate this tectonic scheme (Fig. 2d), with the belts considered separated from each other by the Kuzumaki Tectonic Line (*KTL* in Fig. 2d) and the Taro Tectonic Line (*TTL* in Fig. 2d). Onuki (1969), presumably because of the publication date being close to Yoshida's (1968) paper, summarized the geology of the Kitakami Mountains based on numerous unpublished graduation, Master's, and doctoral theses from Tohoku University. By this time, the distribution area of the North Kitakami, Iwaizumi, and Taro belts was known as the "Northern Kitakami Massif" (e.g., Onuki, 1969 ; Onuki *et al.*, 1960). Sugimoto (1974a, 1974b) mapped the geology of the Iwaizumi and Taro belts and then synthesized new and existing data to represent the various lithologic associations of the Northern Kitakami Massif, as follows : First, the North Kitakami Belt consists mainly of Permian slate and chert with a minor amount of sandstone, schalstein, and limestone. Second, the Iwaizumi Belt is composed of Triassic and Jurassic (and, questionably, Cretaceous) andesitic pillow lavas and large bodies of limestone, with alternating sandstone and slate, chert, and some small bodies of limestone. Finally, the Taro Belt is characterized by Late Jurassic to Cretaceous chert, siliceous shale, slate, greywacke, and alternating slate and sandstone.

Since the introduction of conodont biostratigraphy, Triassic conodonts have commonly been found not only in the Iwaizumi Belt but also in inferred Paleozoic formations in the North Kitakami Belt and in inferred Late Jurassic formations

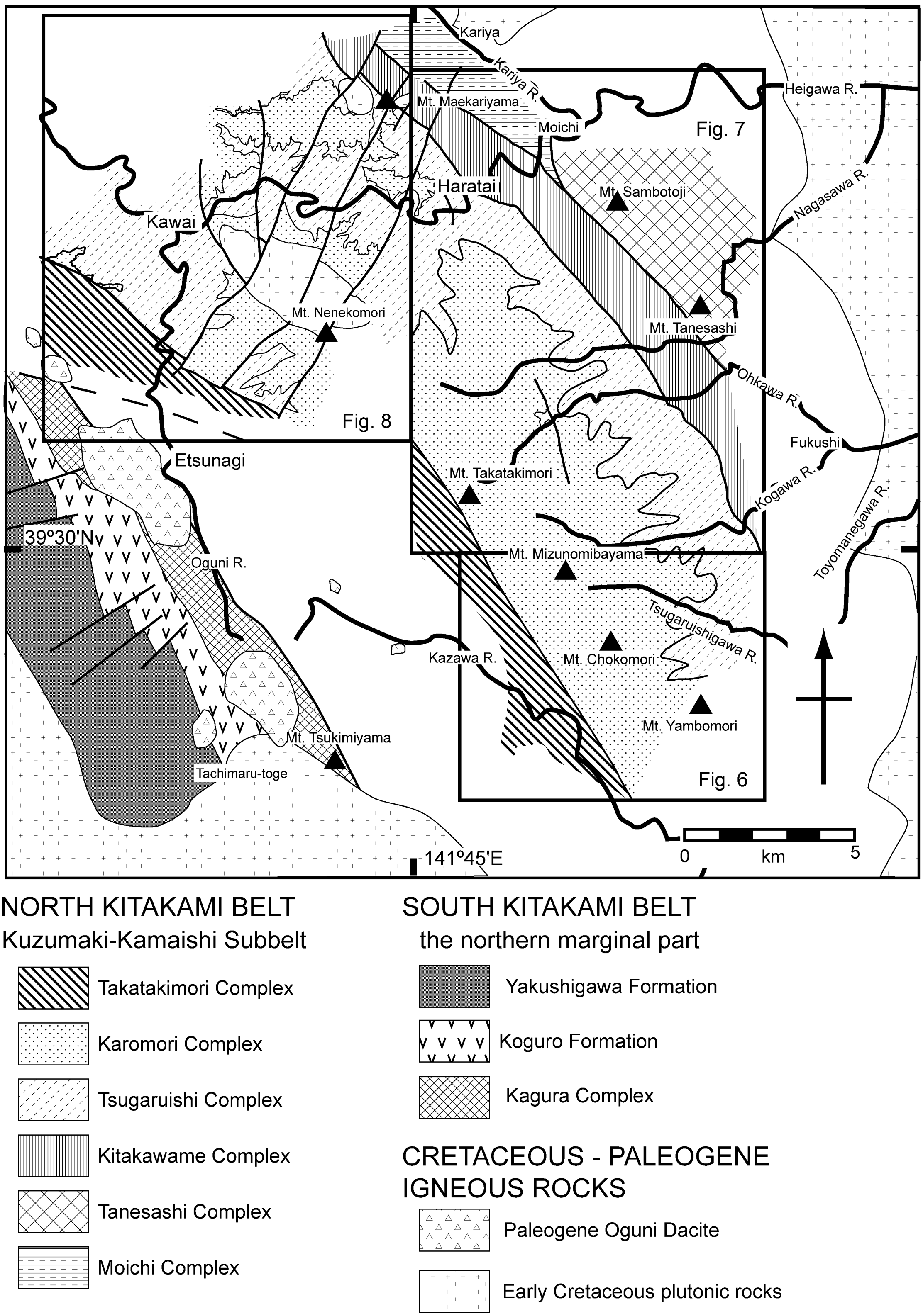


Figure 4. Simplified geologic map of the North Kitakami and South Kitakami belts in the Kawai–Niisato–Miyako areas.

of the Taro Belt (Murata and Sugimoto, 1971 ; Toyohara *et al.*, 1980 ; Yoshida, 1980). Furthermore, extensive geologic mapping and tectonic studies in the Northern Kitakami Massif revealed that both "the Kuzumaki Tectonic Line" and "the Taro Tectonic Line" were tectonically of lesser importance (Yamaguchi, 1981 ; Yamaguchi *et al.*, 1979). This new information led to further revision of the geotectonic framework in the Northern Kitakami Massif. Onuki (1981) suggested that the North Kitakami Belt (NKB in Fig. 2e) was west of the Seki Fault (SF in Fig. 2e) based on the presence of Paleozoic chert. Based on the absence of Paleozoic chert, Onuki (1981) also newly proposed the Akka Belt (AB in Fig. 2e) as the rest of the Iwaizumi Belt described by Yoshida, T. (1968).

Widespread applications of plate tectonics theory and radiolarian-dating methods to Paleozoic geosynclinal sediments of the Japanese islands have shown many to be Mesozoic accretionary complexes (e.g., Taira *et al.*, 1981). Taira *et al.* (1981) also suggested a Mesozoic accretionary complex origin of the Northern Kitakami Massif. This prediction was supported by new and existing data (Minoura 1983, 1985). The Northern Kitakami Massif (which is equivalent to the Northern Kitakami Terrane described by Minoura, 1985) may have formed in an accretionary setting. This hypothesis was also amply confirmed by the recognition of melange or olistostrome facies (Minoura and Tsushima, 1984 ; Oho and Iwamatsu, 1986) and occurrences of Triassic conodonts (Murai *et al.*, 1985, 1986) and Jurassic to Early Cretaceous radiolarians (Matsuoka 1987, 1988 ; Matsuoka and Oji, 1990 ; Minoura and Tsushima, 1984).

Minoura (1985) considered the Northern Kitakami Massif to be a single zone. However, Okami and Ehiro (1988) pointed to differences in the petrogenetic composition of sandstone and in block ages between western and eastern areas of the northern Kitakami Massif, leading to a redefinition of the subdivision of the northern Kitakami Massif. The Kuzumaki- Kamaishi Belt (KKs in Fig. 2f) largely correlates with the North Kitakami Belt of Yoshida (1968) and the western part of the Iwaizumi Belt. The Akka-Tanohata Belt (ATs in Fig. 2f) correlates with the eastern part of the Iwaizumi Belt and the Taro Belt.

This historical review shows that many previous papers have used "North Kitakami Belt" to name the entire area of the northern Kitakami Massif and that this erroneous usage has become established. Considering the historical and current uses of these tectonic division terms, Ehiro *et al.* (2005) proposed a new standard tectonic divisional scheme for the Kitakami Massif (Fig. 2f) : the North Kitakami Belt (NKB in Fig. 2f), Nedamo Belt (NB in Fig. 2f), and South Kitakami Belt (SKB in Fig. 2f), of which the North Kitakami Belt is subdivided into two subbelts. We follow their scheme in this paper.

3. Geological setting and brief geologic framework

3.1. Terminology

Field mapping has been performed in the southeastern part of the Kuzumaki-Kamaishi Subbelt in the (1) Toyomane-Kazawa, (2) southeast Moichi, (3) southwest Moichi, (4) northwest Moichi, and (5) Kawai areas (Fig. 3). The Kuzumaki-Kamaishi Subbelt is composed largely of discontinuous, disrupted blocks and melanges. The facies, like the accretionary complexes, do not yet have formal stratigraphic schemes in the International Stratigraphic Guide (Salvador, 1994), and appropriate stratigraphic schemes for the accretionary complexes have not been formally proposed yet. Instead, a tectonostratigraphic unit having a series of common lithologic associations distributed in some extant areas has been tentatively called a "unit" by Wakita (1988), "complex" by Nakae (2000), and "formation" and "group" by Yamakita and Otoh (2001). Although a formal stratigraphic division for the accretionary complex has not yet been ratified by the International Stratigraphic Committee, in this paper we use "subcomplex" to refer to a package of some characteristic lithologic associations and "complex" to indicate a set of "subcomplexes."

Accretionary complexes show lithologically complex patterns due to varying degrees of deformation ; the expressions of particular modes of occurrences are given by several terms, listed below :

- *Mixed rock* : Descriptive term for a lithologic body of monomictic or polymictic blocks in a fine-grained matrix, regardless of tectonic, landslide, or other origins. Conglomerates are excluded from mixed rock.
- *Melange* : Mixed rock with shear structures. Blocks are difficult to show at a map scale of 1 : 25,000.
- *Slaty cleavage* : A pervasive, parallel foliation of fine-grained, platy minerals in a direction perpendicular to the direction of maximum finite shortening in rocks.
- *Block* : Allotropic or autochthonous lithologic bodies larger than their matrix, embedded in mixed rock.
- *Lens* : Blocks visible by the naked eye but smaller than a slab.
- *Slab* : Blocks of mappable size at a map scale of 1 : 25, 000.
- *Clast* : Small blocks invisible to the naked eye.
- *Chert-clastics sequence* : The oceanic-plate stratigraphy that starts from oceanic basalts and overlying chert, followed by siliceous mudstone and upwardly coarsening siliciclastic rocks such as sandstone. Lithologic changes record the travel history of oceanic plates from ridge to trench (Matsuoka, 1989 ; Matsuda and Isozaki, 1991).

3.2. Geologic settings

We newly subdivide the accretionary complex in the southeastern part of the Kuzumaki-Kamaishi Subbelt into six complexes : the Moichi, Tanesashi, Kitakawame, Tsugaruishi, Karomori, and Takatakimori Complexes (Figs. 4-12, Table 1). The Moichi Complex is located in the northeastern part of the study area and is characterized by alternating sandstone and mudstone, with occasional occurrences of chert blocks and intraformational conglomerate. This lithologic association is named the Kariya Subcomplex and is the only subcomplex recognized in the Moichi Complex (Fig. 5). This complex is in fault contact with the Tanesashi Complex to the east. The southern part of the Moichi Complex tectonically overlies the Tanesashi Complex in the southern

Table 1. Geographic names in the study area (Japanese and English).

English name	Japanese name	English name	Japanese name
Asse-no-sawa Valley	安瀬ノ沢	Maekariyama, Mt.	前刈山
Choukomori, Mt.	鳥古森	Matachisawa Valley	又地沢
Fujibiransawa Valley	藤ビラン沢	Mitsuishi	三ツ石
Fukado	深戸	Moichi	茂市
Fukaisawa Valley	フカイ沢	Nagasawarokkumi	長沢六組
Fukushi	福士	Nagasawagawa River	長沢川
Furuyadomori, Mt.	古宿森	Nakanomatazawa Valley	中の又沢
Futta	古田	Nashigahorasawa Valley	ナシガホラ沢
Haigura Mine	灰倉鉱床	Nawauchisawa Valley	ナワウチ沢
Hanawa	花輪	Nekoezawa	ネコエ沢
Haratai	腹帯	Nenekomori, Mt.	禰々子森
Heigawa River	閉伊川	Niisato Village	新里村
Hikime	蟇目	Oh'horazawa	大洞沢
Hon'munesawa	ホンムネ沢	Ohsawa Valley	大沢
Horochi	袰地	Ohtanichi	大谷地
Horoiwa	袰岩	Ohtanichizawa Valley	大谷地沢
Horoya	袰屋	Okudairasawa Valley	奥平沢
I'hinotairasawa Valley	イヒノタイラ沢	Ozuchi	大槌
Itamotosawa Valley	板本沢	Oriawase Valley	折合沢
Iwatanisawa Valley	岩谷沢	O'shounaisawa Valley	オショウナイ沢
Kai-kaminosawa Valley	界上の沢	Saike	西家
Kaizawa Valley	界沢	Sen'notairasawa Valley	栓ノタイラ沢
Kakunosawa Valley	カクノ沢	Shimokawai	下川井
Kami'okutorisawa Valley	カミオクトリ沢	Shimo-Kobayorizawa Valley	下古場寄沢
Kaneyamazawa Valley	カネ山沢	Shimonosawa Valley (in the northern east part of the Moichi area)	シモノ沢
Kariya	刈屋		
Kariya River	刈屋川	Shimonosawa Valley	下の沢
Karodake, Mt.	霞露岳	Shoudonosawa Valley	小土ノ沢
Karosawa Valley	カロ沢	Suijin	水神
Karomori, Mt.	加呂森	Su'naizawa Valley	巣内沢
Katasu	片巣	Takinosawa Valley	滝ノ沢
Kawai	川井	Tanosawa Valley	田の沢
Kawai-minamizawa Valley	川井南沢	Tokakemesawa Valley	トカケメ沢
Kawai Quarry	川井採石場	Toyomane	豊間根
Kawai-o'hashi Bridge	川井大橋	Uchinosawa	内の沢
Kazawa	金沢	Unedoriyama, Mt.	宇根鳥山
Kebaraichi	花原市	Urushizawa Valley	ウルシ沢
Kedamonosawa Valley	ケダモノ沢	Ushibushisawa Valley	牛伏沢
Kita'isawa Valley	北井沢	Waka'anasawa Valley	若穴沢
Kitakawame	北川目	Warabinosawa Valley	蕨ノ沢
Kitakawamesawa Valley	北川目沢	West Nashigahorasawa Valley	ナシガホラ西沢
Kitsubushisawa Valley	キツブシ沢	Yakatagasawa Valley	舘ヶ沢
Kogawa Valley	小川	Yamada Town	山田町
Komatsugura	小松倉	Yamadabatasawa Valley	山田バタ沢
Komatsugurasawa Valley	小松倉沢	Yam'bo-mori, Mt.	ヤンボ森
Koshika'uchisawa Valley	小鹿内沢	Yasomori, Mt.	弥惣森
Kotanichisawa Valley	小谷地沢	Yoshibesawa Valley	吉部沢
Kuranosawa Valley	倉ノ沢	Yukihira Valley	ユキヒラ沢
Kurihorasawa	クリホラ沢	Yumenukihirasawa Valley	ユメヌキヒラ沢

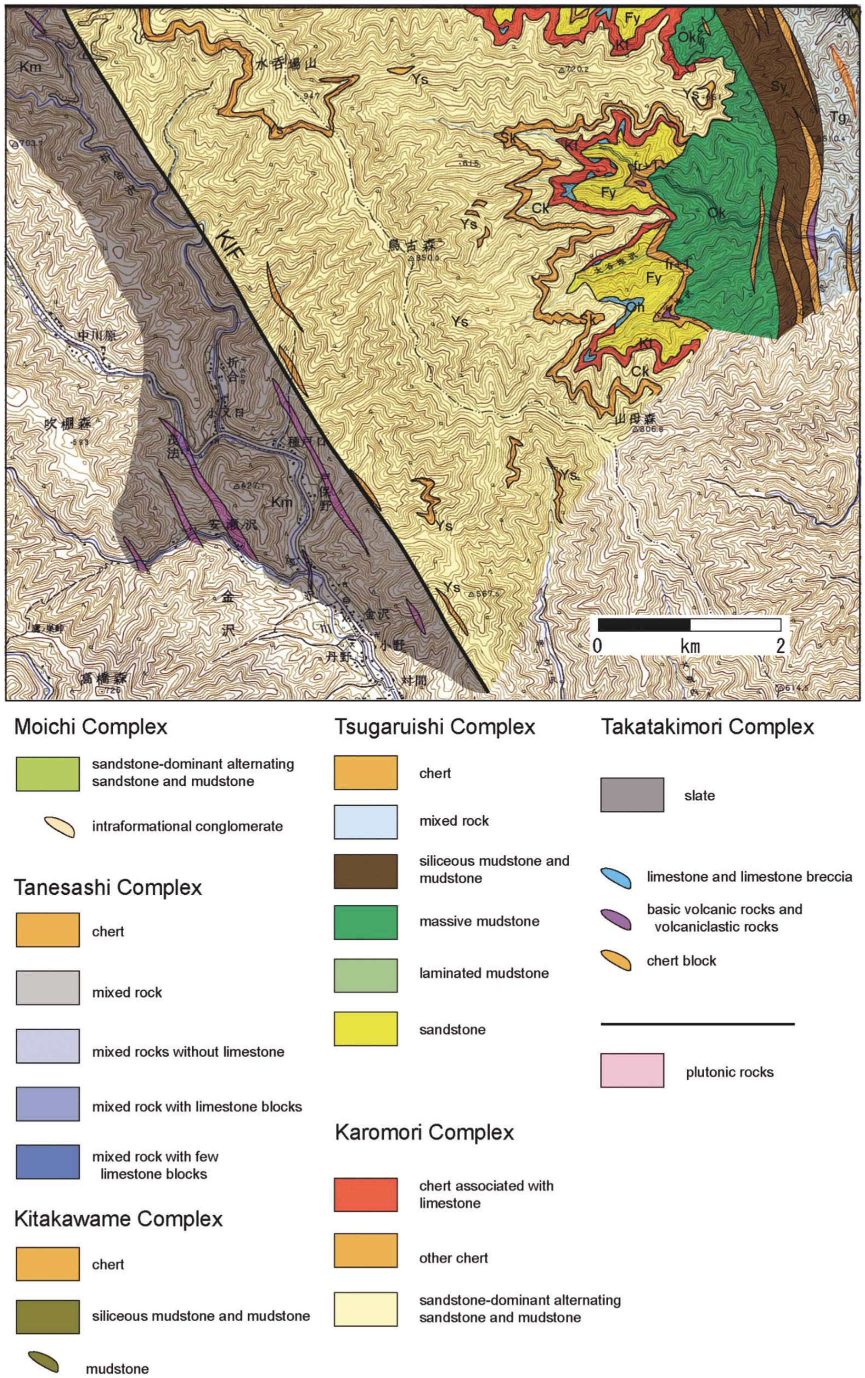
Moichi area.

The Tanesashi Complex has a wide distribution in the eastern part of the study area (Fig. 4) and is composed of low- angle tectonostratigraphic units of melanges and large chert slabs, namely the Nagasawarokkumi, Minamikawame, Komatsugura, and Sambotoji Subcomplexes, from lower to upper (Figs. 5–9). The eastern part of the Tanesashi Complex was intruded with Early Cretaceous plutonic rocks called the Miyako Pluton. The southwestern edge of the Tanesashi Complex is in fault contact with the Kitakawame Complex by the subvertical dipping and NNW-trending Horochi Fault (HOF in Fig. 7). The Nagasawarokkumi Subcomplex is comprised of melange containing minor amounts of chert and sandstone blocks with a fine-grained matrix. The Minamikawame Subcomplex tectonically overlies the Nagasawarokkumi Subcomplex, which is comprised of imbricated thin blocks of ribbon chert. The Minamikawame Subcomplex is structurally covered with the Komatsugura Subcomplex that yields chert, sandstone, mudstone, and limestone blocks in a fine-grained matrix and is marked by

Complex	Subcomplex (Sc.)	Lithology
The South Kitakami Belt	Kagura Complex（神楽複合岩類）	dolerite, gabbro, trondhjemite, and ultrabasic rocks
The Hayachine Eastern Marginal Fault（早池峰東縁断層）		
The Kuzumaki-Kamaishi Subbelt		
Takatakimori Complex（高滝森コンプレックス）	Kirinai Sc.（桐内＊） Ki / Komataguchi Sc.（小又口＊） Km	phylletic mudstone with chert, tuff, and sandstone lenses
The Kirinai Fault（桐内断層）		
Karomori Complex（加呂森コンプレックス）	Yasomori Sc.（弥惣森＊） Ys	several sets of chert-clastic sequences (30-1000 m)
	Shiraitotaki Sc.（白糸滝＊） Sk	ribbon chert (ca. 30 m)
	Choukomori Sc.（鳥古森＊） Ck	sandstone-dominant clastic rocks (50-1000m)
	Kotanichi Sc.（小谷地＊） Kt	ribbon chert associate with Lower Permian limestone and mafic volcanic rocks (50-450m)
Tsugaruishi Complex（津軽石コンプレックス）	Furuyadomori Sc.（古宿森＊） Fy	sandstone-dominant alternating sandstone and mudstone, with several horizons of ribbon chert (50-1000m)
	Fukushi Sc.（福士＊） Fk	millimeter- to centimeter-scale, parallel-laminated mudstone (100-900m)
	Okudaira Sc.（奥平＊） Ok	massive black mudstone, and bedded siliceous mudstone (200-270 m)
	Sippyou Sc.（シッピョウ＊） Sy	a repetition of chert-clastic sequences with occaional manganese nodules (350-700 m)
	Taguri Sc.（タグリ＊） Tg	melange with blocks of chert, siliceous mudstone, and sandstone (130-390 m)
The Warabinosawa Fault（蕨ノ沢断層）		
Kitakawame Complex（北川目コンプレックス）	Shimochi Sc.（霜地＊） Sm	ribbon chert with the limestone breccia (200-430 m)
	Nagaiwamori Sc.（長岩森＊） Nw	a repetition of chert-clastic sequences (> 2000 m)
The Horochi Fault（褒地断層）		
Moichi Complex（茂市コンプレックス）	Kariya Sc.（刈屋＊） Ka	alternating sandstone and mudstone with occasional intraformational conglomerate (> 2000 m)
Tanesashi Complex（種差コンプレックス）	Sambotoji Sc.（サンボトジ＊） Sb	ribbon chert and the overlying homogenous mudstone (>30 m)
	Komatsugura Sc.（小松倉＊） Ks/Kr	melange with chert slab (ca. 500 m)
	Minamikawame Sc.（南川目＊） Mi	thick chert slab (10 m)
	Nagasawarokkumi Sc.（長沢六組＊） Ns	melange (>100 m)

＊サブコンプレックス

Figure 5. Tectonostratigraphic divisions of the study area. Abbreviations of each subcomplex correspond to those in other figures in this paper.



Abbreviations:
Ck: Choukomori Formation, Fk: Fukushi Formation, Fy: Furudyadomori Formation, Ka: Kariya Formation, Ki: Kirinai Formation, Km: Komataguchi Formation, Kr: middle Komatsugura Formation, Ks: upper/lower Komatsugura Formation, Kt: Kotanichi Formation, Mi: Minamikawame Formation, Nw: Nagaiwamori Formation, Ns: Nagasawarokkumi Formation, Ok: Okudaira Formation, Sb: Sambotoji Formation, Sk: Shiraitotaki Formation, Sm: Shimochi Formation, Sy: Sippyou Formation, Tg:Taguri Formtion, Ys: Yasomori Formation.

HOF: Horichi Fault, KAF: Kariya Fault, KIF: Kirinai Fault, KOF: Komatscugura Fault, NAF: Nakanomata Fault, NKF: Nakakawai Fault, SAF: Saike Fault, SKF: Shimokawai Fault, WAF: Warabinosawa Fault

fr+1, fr+2: chert+1 and chert 2 horizons in the Furuyadomori Formation.

Abbreviations for lithology. ch: chert, cg: conglomerate, ls: limestone.

Figure 6. Geologic map of the southern Toyomane–Kazawa area. The base map is after the 1 : 50,000-scale topographic quadrangle map “Otsuchi” by the Geographic Survey Institute of Japan.

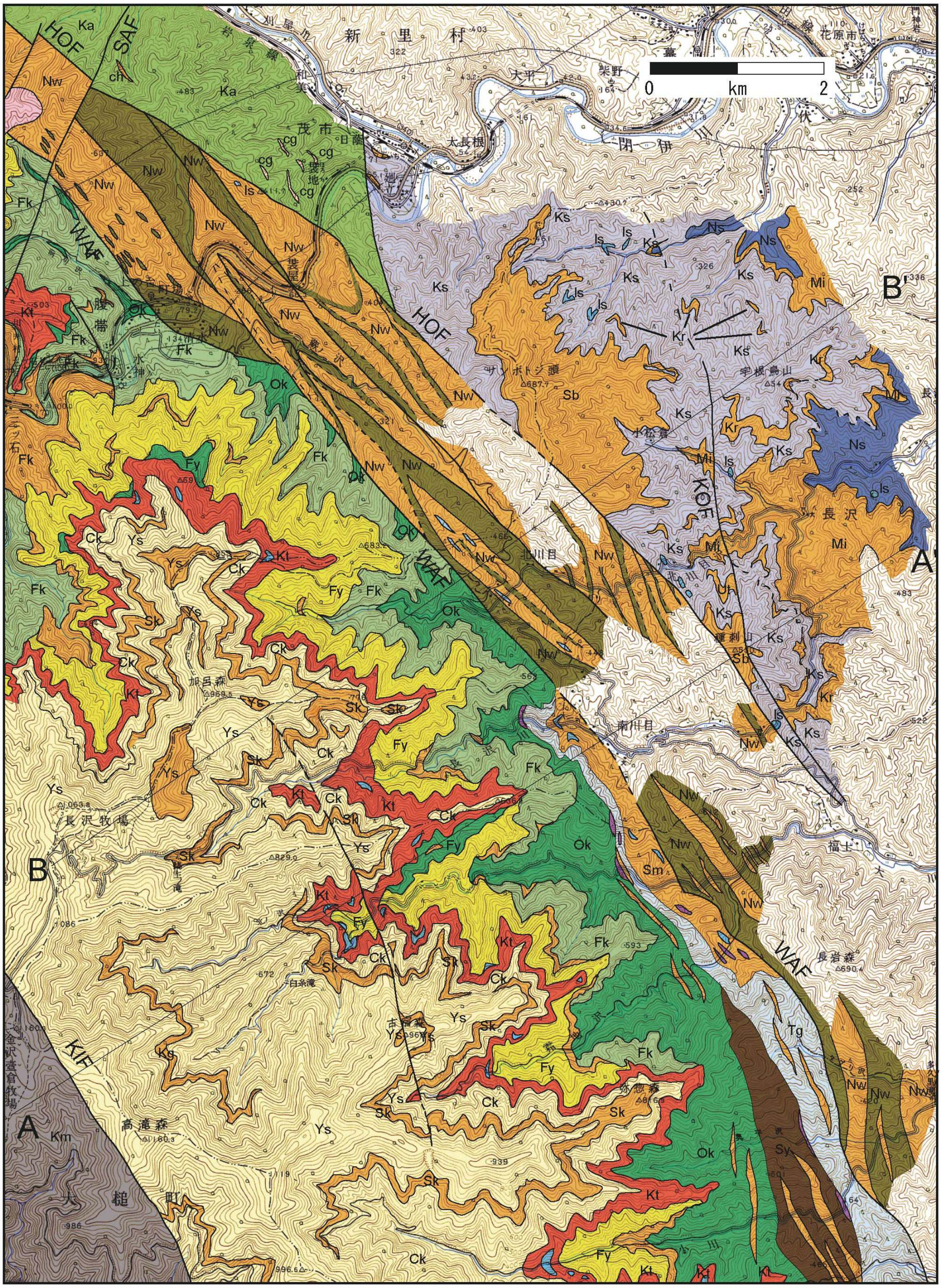


Figure 7. Geologic map of the northern Toyomane-Kazawa and Moichi areas. Base maps are after the 1 : 50,000-scale topographic quadrangle maps "Otsuchi" (to the south) and "Miyako" (to the north) by the Geographic Survey Institute of Japan. Abbreviations and the legend are shown in Figure 6.

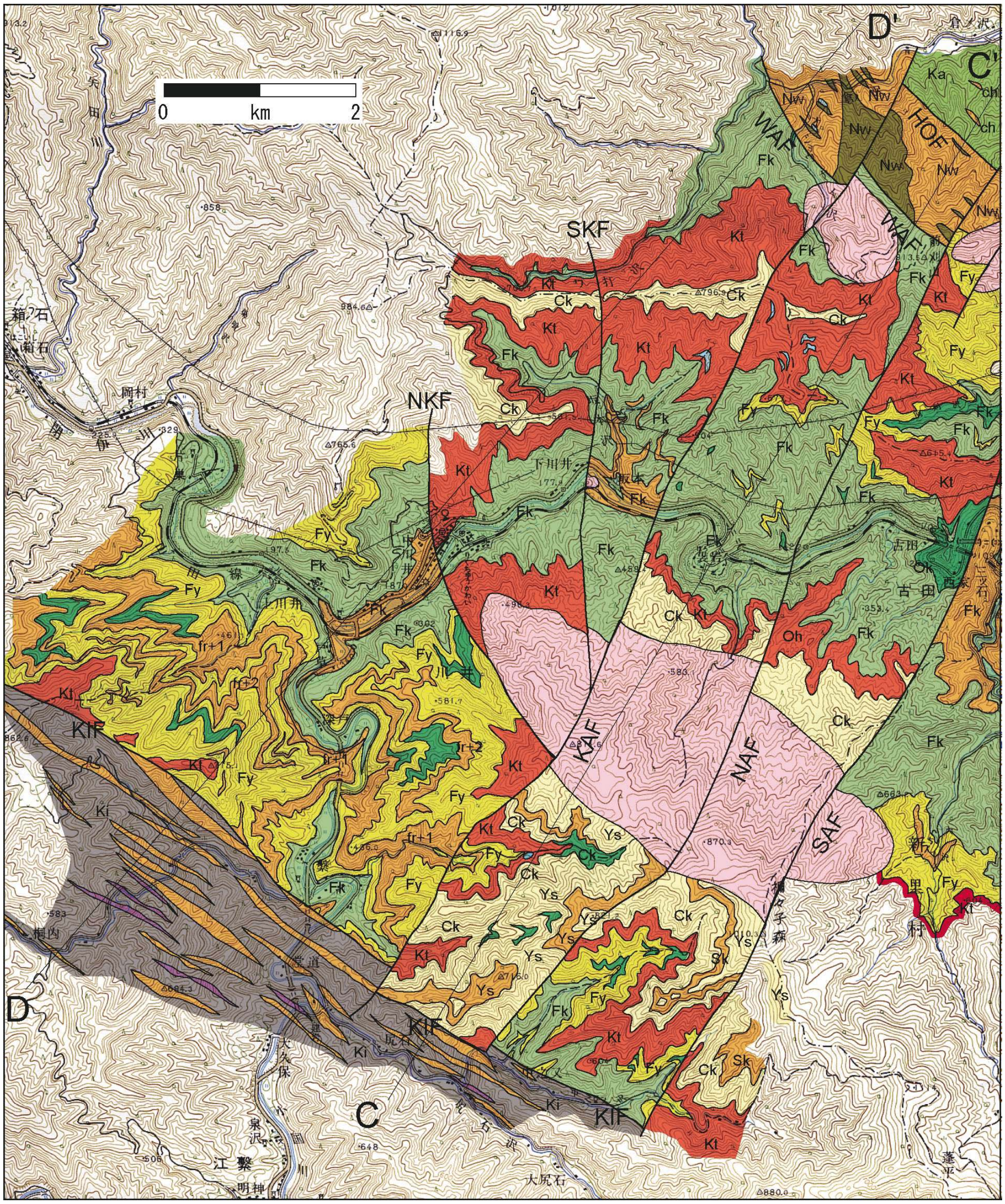


Figure 8. Geologic map of the western Moichi and Kawai areas. Base maps are after the 1 : 50,000-scale topographic quadrangle maps “Miyako” (to the east) and “Kawai” (to the west) by the Geographic Survey Institute of Japan. Abbreviations and the legend are shown in Figure 6.

a discontinuous chert horizon near the base of the melange formation. The Komatsugura Subcomplex is structurally overlain by the white ribbon chert of the Sambotoji Subcomplex, which is generally found at higher altitude locations in this area.

The Kitakawame Complex, a belt 1.5–2.0 km in width, striking NNW, and dipping subvertically (Fig. 9), is bounded to the east by the Horochi Fault and to the west, partly, by the Warabinosawa Fault (WAF in Fig. 7). This complex is subdivided into the Nagaiwamori Subcomplex, a series of chert–clastics sequences, and the Shimochi Subcomplex, a series of chert–clastics sequences with a Mesozoic limestone breccia (Fig. 5). The Shimochi Subcomplex is also patchily recognizable in the eastern Toyomane-Kazawa area (Figs. 6, 7).

The Tsugaruishi Complex adjacent to the Kitakawame Complex is dominated by repeated, coherent packages of clastic rocks, chert–clastics sequences, and ribbon cherts. This complex consists of the Taguri, Sippyou, Okudaira, Fukushi, and Furuyadomori Subcomplexes (Fig. 5). All of

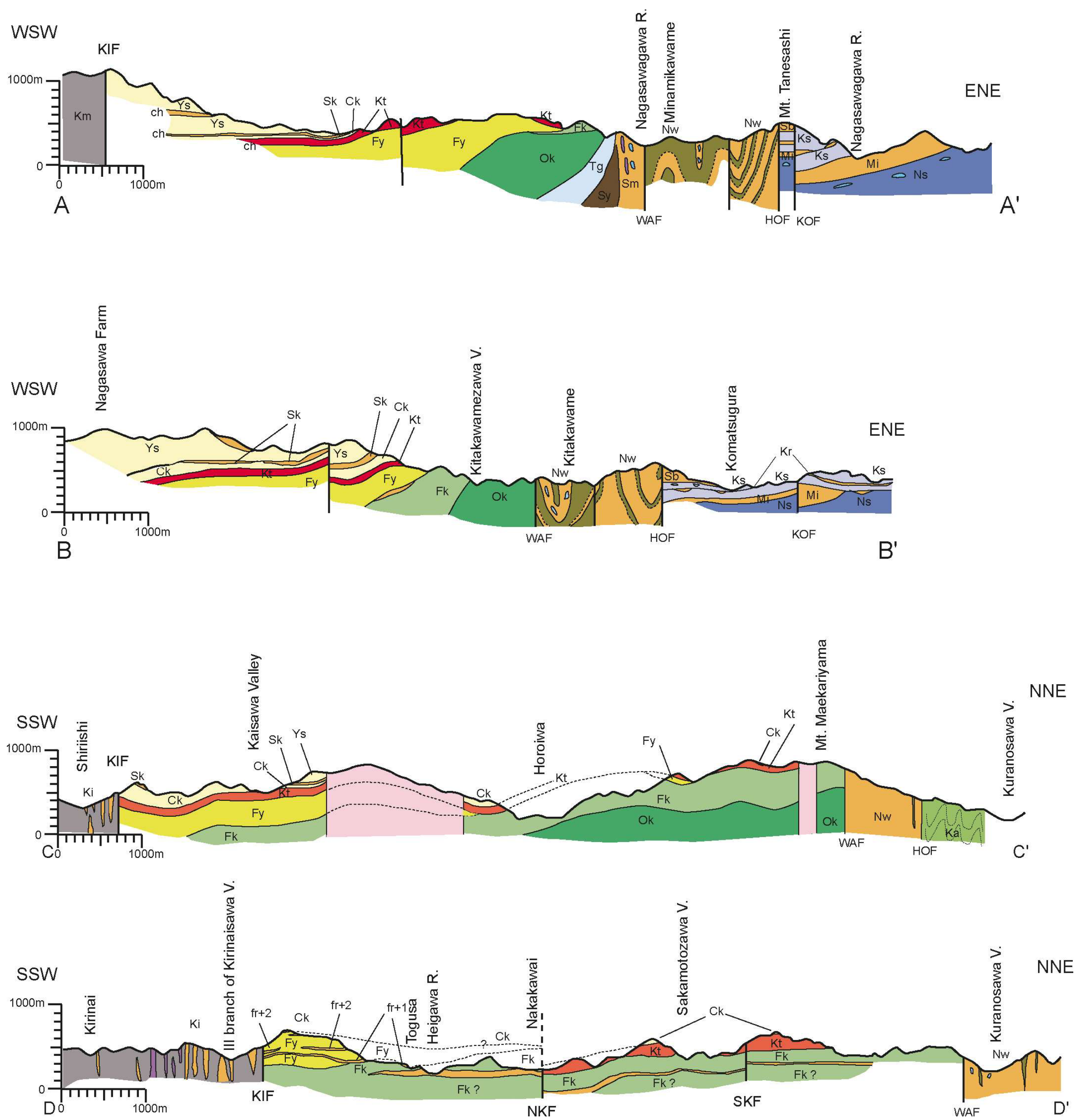


Figure 9. Geologic cross-sections across the Kuzumaki-Kamaishi Subbelt. Section lines are depicted in Figures 7 (for A-A′ and B-B′ sections) and 8 (for C-C′ and D-D′ sections). Abbreviations and the legend are shown in Figure 6.

the subcomplexes are separated from each other by probable faults. These subcomplxes usually dip very shallowly to the west at a mappable scale, but the eastern marginal part of this complex gradually becomes vertical (Fig. 9). The Taguri Subcomplex is a melange formation with blocks of chert, siliceous mudstone, and sandstone, and is in fault contact with the Sippyou Subcomplex to the west. The Sippyou Subcomplex is characterized by the repetition of a chert-clastics sequence. The Okudaira Subcomplex tectonically overlies the Taguri and Sippyou Subcomplexes and is dominated by massive black mudstone intercalated with discontinuous sandstone layers. The Okudaira Subcomplex is structurally overlain by the Fukushi Subcomplex, which is composed of millimeter-scale parallel-laminated mudstone with a small amount of alternating sandstone and mudstone. The Fukushi Subcomplex is structurally covered by the Furuyadomori Subcomplex, which is characterized by sandstone-dominant alternating sandstone and mudstone. The Furuyadomori Subcomplex is locally dominated by mudstone and is locally intercalated with many chert horizons in the Kawai area (Fig. 8).

The Karomori Complex, which structurally overlies the Tsugaruishi Complex, dips very shallowly to the west and is divided into the Kotanichi, Choukomori, Shiraitotaki, and

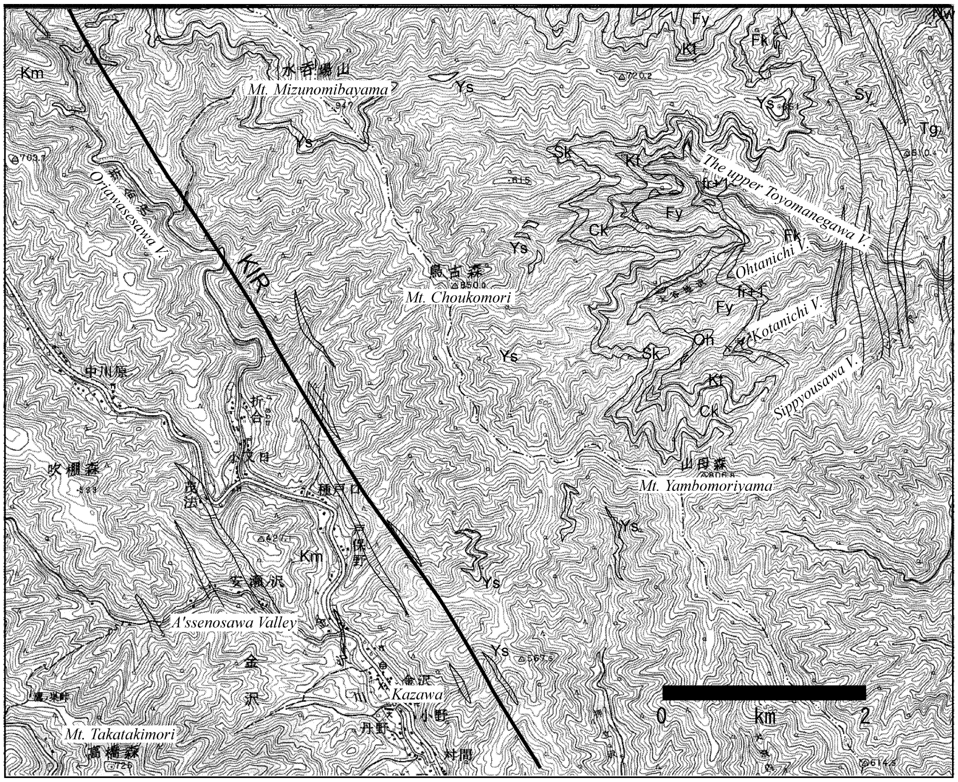


Figure 10. Index map of geographic names in the southern Toyomane-Kazawa area, indicating stratigraphic boundaries and names. The base map is after the 1 : 50,000-scale topographic quadrangle map "Otsuchi" by the Geographic Survey Institute of Japan.

Yasomori Subcomplexes (Fig. 5). The Kotanichi Subcomplex consists mainly of white to gray ribbon chert associated with blocks of Early Permian limestone and greenstone, and is overlain structurally with the Choukomori Subcomplex that is dominated by sandstone-dominant clastic rocks with rip-up clasts. The Shiraitotaki Subcomplex, which overlies the Choukomori Subcomplex, is characterized by black ribbon chert. The Yasomori Subcomplex is defined by several sets of chert-clastics sequences, above the black chert of the Shiraitotaki Subcomplex.

The Takatakimori Complex is characterized by slate. It is bounded from the Tsugaruishi and Karomori Complexes to the east by the Kirinai Fault (KIF in Figs. 6-9), and from the northern margin of the South Kitakami Belt to the west by the Hayachine Eastern Marginal Fault (Ehiro *et al.*, 1988 ; Okami and Ehiro, 1988). Although two subcomplexes are identified as the Kirinai and Komataguchi Subcomplexes in the Takatakimori Complex, the exact relationship between these subcomplexes remains unknown (Fig. 5).

4. Formations

4.1. The Moichi Complex (new)

4.1.1. Kariya Subcomplex (new ; Abbreviation on the geologic map : Ka)

Type locality : Along the northern branch of the Shimono-kitasawa Valley in the northeastern part of northwestern Moichi (Figs. 7, 11)

Definition : The Kariya Subcomplex is defined by alternating sandstone and mudstone, with intraformational conglomerates and a small amount of chert blocks.

Distribution : The Kariya Subcomplex crops out along the Kariya River, the valleys west of the Kariya River (Fig. 13a), and the eastern part of the Koshika'uchisawa Valley.

Lithology : This subcomplex is dominated by alternating sandstone and mudstone (Fig. 14). The sandstone is light-gray to gray, coarse- to fine-grained feldspathic wacke, while the mudstone is black and intercalated with millimeter- to centimeter-scale sandstone laminae. Sandstone beds are in contact with mudstone beds by a very sharp boundary. Slaty cleavages are invisible to the naked eye, and only recognizable in thin sections by microscopy. Chert blocks are infrequently found in the subcomplex. This subcomplex generally strikes N-S to NNW-SSE and dips 40-60- east or west. It is sporadically intercalated with conglomerate layers that are poorly sorted with abundant sandstone and chert cobbles, and with minor granodiorite and porphyrite cobbles in a mudstone matrix (Fig. 14d).

Main outcrops : Alternating sandstone and mudstone crop out at the type locality, the northern branch of the Shimono-kitasawa Valley. Bed thicknesses vary from 1-10 m. In this valley, mudstone is occasionally intercalated with discontinuous sandstone laminae. The sandstone is gray, very fine- to medium-grained feldspathic wacke. North-

Figure 11. Index map of geographic names in the northern Toyomane-Kazawa and Moichi areas, indicating stratigraphic boundaries and names. Base maps are after the 1 : 50,000-scale topographic quadrangle maps "Otsuchi" (to the south) and "Miyako" (to the north) by the Geographic Survey Institute of Japan. Abbreviations are shown in Figure 10.

Figure 12. Index map of geographic names in the western Moichi and Kawai areas, indicating stratigraphic boundaries and names. Base maps are after the 1 : 50,000-scale topographic quadrangle maps "Miyako" (to the east) and "Kawai" (to the west) by the Geographic Survey Institute of Japan. Abbreviations are shown in Figure 10.

northwest-striking vertical faults are occasionally found in this valley. Similar lithology is found in the Takinosawa Valley (Fig. 13), the Kita'isawa Valley, and along a lower 700-m interval from the mouth of the Kedamonosawa Valley.

Along western 100-m intervals from the mouth of the Kuranosawa Valley, alternating beds of sandstone and mudstone are exposed on the riverbed of the valley. There are no outcrops in the subsequent western 800-m intervals. The alternating medium- to coarse-grained sandstone (each bed attains a thickness of ca. 1 m) and black massive mudstone (ca. 10 cm thick) strikes N 20°W and dips 40°W near the middle Kuranosawa Valley. In the Yakatagasawa Valley, alternating sandstone and black massive mudstone crop out. A chert block ranging from 1 to 10 m thick is found in this valley.

Alternating gray to light-gray, very fine- to medium-grained sandstone and gray, massive mudstone is exposed along a roadside in the Shoudonosawa Valley (Fig. 13b). These alternating beds are dominated by mudstone in the lower part of the valley and by sandstone in the middle and

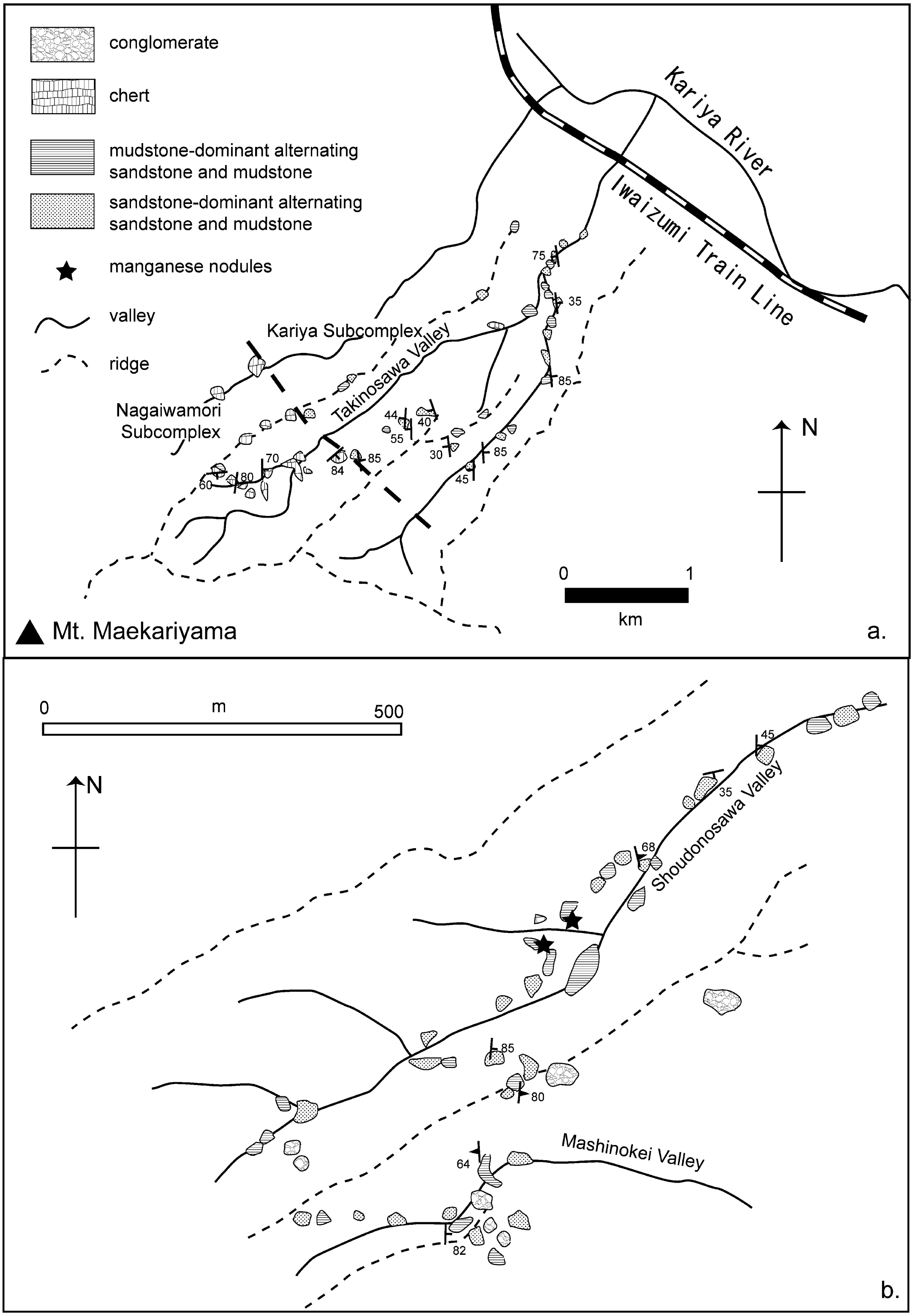


Figure 13. Field map showing the distribution of outcrops and boundaries of lithologic units (a) in the Takinosawa Valley and (b) in the Shoudonosawa Valley.

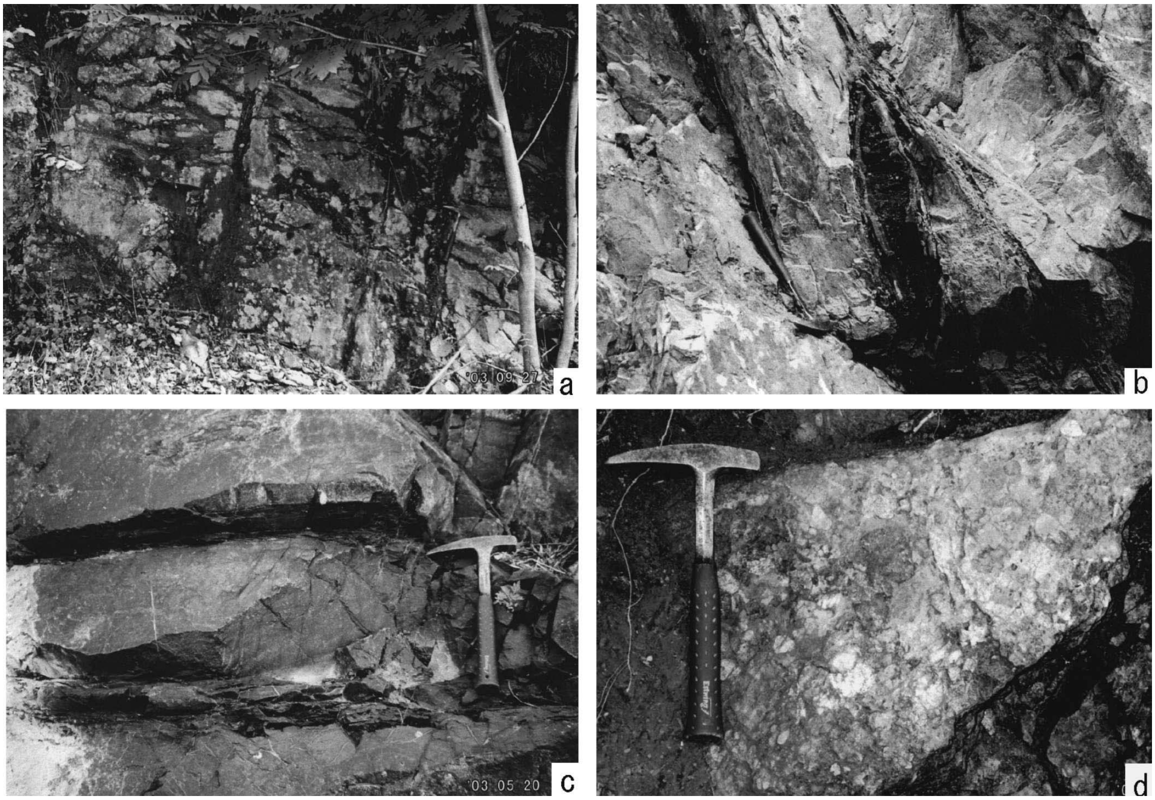


Figure 14. (a) Sandstone-dominant, alternating sandstone and mudstone of the Kariya Subcomplex in the Kuranosawa Valley. (b) A manganese nodule in the mudstone of the Kariya Subcomplex in the middle Shoudonosawa Valley. (c) Sandstone-dominant, alternating sandstone and mudstone of the Kariya Subcomplex along the Kariya River. (d) Conglomerate with a mudstone matrix of the Kariya Subcomplex in the middle Shoudonosawa Valley. For scale, the length of the hammer handle is 30 cm.

upper parts of the valley. The sandstone-dominant alternating sandstone and mudstone is partly crushed at the end of the valley. Mudstone in the Shoudonosawa Valley is marked by the presence of manganese nodules (Fig. 14b) and intraformational conglomerate beds. The manganese nodules are found in mudstone at 200 m elevation, whereas conglomerate beds are observed at elevations from 250 to 300 m (Fig. 14d). A few outcrops of the sandstone-dominant alternating sandstone and mudstone are found near the city of Moichi. Mudstone-dominant alternating sandstone and mudstone crop out along the roadside at elevations lower than 130 m on the right bank of the Heigawa River, south of Horochi. Sandstone in the alternating beds has been slightly flattened by deformation. A N 30°W striking and eastward dipping fault with gouge ranging from 2 to 4 m thick and consisting of broken sandstone, mudstone, and chert blocks is exposed at elevations of 130–400 m.

Thickness : The Kariya Subcomplex is repeated by tight folding at a half-wavelength for several tens of meters. The apparent thickness of the subcomplex exceeds 2000 m, although the eastern boundary of the subcomplex is located outside the study area.

Contact : The Kariya Subcomplex and Kitakawame Complex are divided by the Horochi Fault, which has a 100-m-thick gouge in the Shoudonosawa and Koshika'uchisawa valleys (Figs. 13a, 21d). This gouge consists of crushed sandstone, mudstone, and chert. The boundary between the Kariya and Nagasawarokkumi Subcomplexes was observed on the right bank of the Heigawa River, south of Horochi, where is faulted. The Kariya Subcomplex structurally overlies the Komatsugura Subcomplex with a strike of N 30°W and dip of 45–50°W.

Comparison : This subcomplex is lithologically similar to the clastic rocks of the Furuyadomori Subcomplex, but can be distinguished from the latter in that the Kariya Subcomplex is separately distributed in the northwestern Moichi area. The conglomerate composition also differs between the subcomplexes : the conglomerates of the Furuyadomori Subcomplex contain chert breccia, whereas those of the Kariya Subcomplex contain various lithologic materials, including chert.

Fossils and age : Poorly preserved, multi-segmented nassellarians of probable Mesozoic age are found in very fine-grained sandstone in the upper part of the Shoudonosawa Valley.

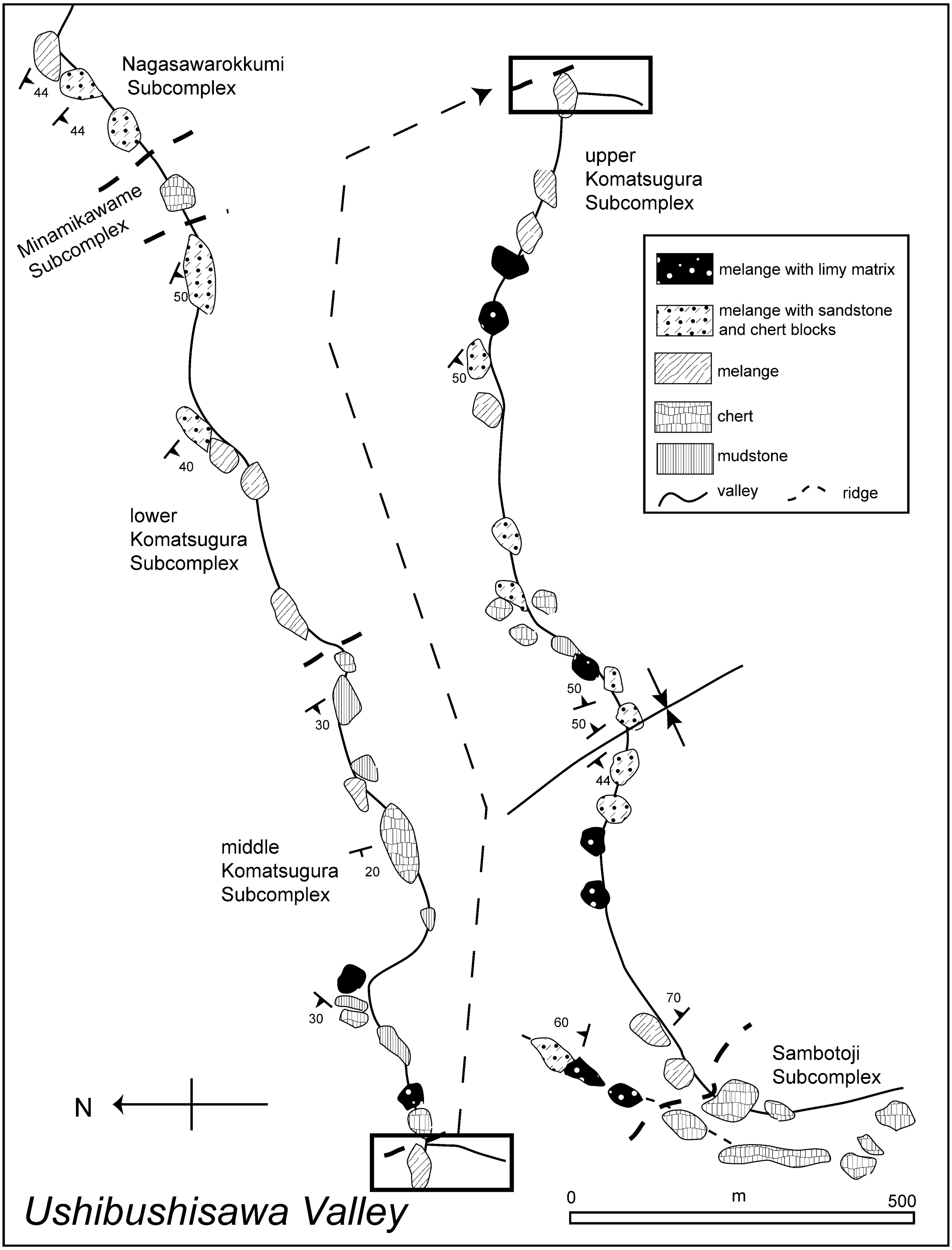


Figure 15. Field map showing the distribution of outcrops of the Komatsugura and Minamikawame Subcomplexes in the Ushibushi Valley.

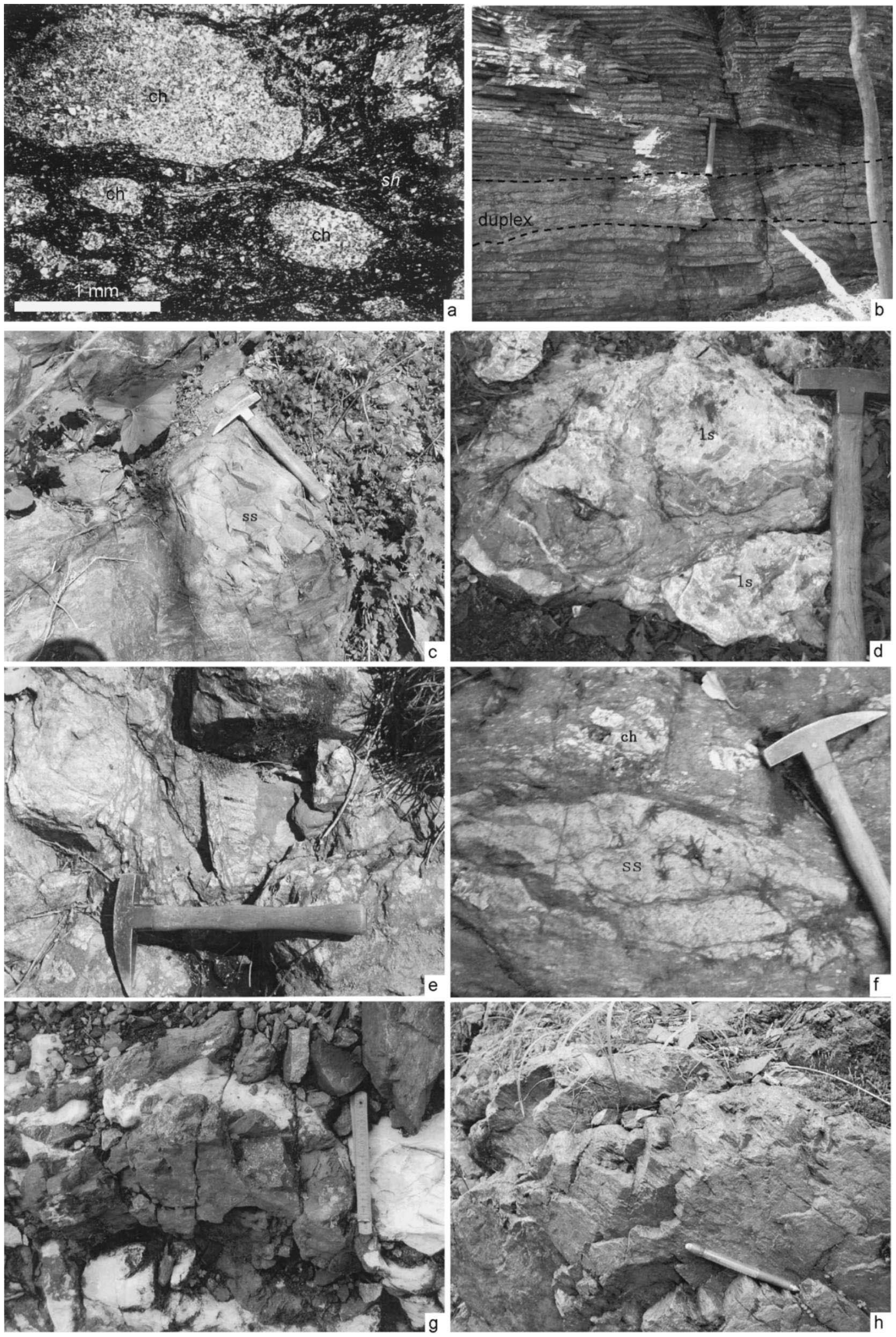


Figure 16. (a) Shear band cleavage (*sh*) and shear clast of chert (ch) in a melange of the Nagasawarokkumi Subcomplex. Crossed polars. (b) Ribbon chert of the Minamikawame Subcomplex in the north IV branch of the Komatsugurasawa Valley. (c) Mixed rock with sandstone blocks (ss) of the lower Komatsugura Subcomplex in the north IV branch of the Komatsugurasawa Valley. (d) Mixed rock with limestone blocks (ls) of the lower Komatsugura Subcomplex in the north branch of the Kitakawamesawa Valley. (e) Mixed rock with chert clasts (light-colored part) of the lower Komatsugurasawa Subcomplex in the II branch of the Ushibushisawa Valley. (f) Mixed rock with sandstone (ss) and chert (ch) blocks of the upper Komatsugura Subcomplex in the II branch of the Ushibushisawa Valley, (g) limestone-volcanic rocks bearing breccia of the upper Komatsugura Subcomplex in the South II branch of the Kitakawamesawa Valley. For scale the length of the ruler is 16 cm. (h) Well-developed cleavages in the mudstone of the lower Komatsugura Subcomplex in the west II branch of the Minamikawame Valley. For scale, the length of the pencil is 15 cm ; the length of the hammer handle is 30 cm, unless otherwise indicated.

4.2. Tanesashi Complex (new)

4.2.1. Nagasawarokkumi Subcomplex (new ; Ns ; Fig. 7)

Type locality : Nagasawarokkumi in the southeastern Moichi area (Fig. 17).

Definition : Melange facies (Fig. 16a) distributed in lower elevation areas of the southeastern Moichi area.

Lithology : The Nagasawarokkumi Subcomplex contains a minor amount of chert and sandstone blocks (several up to 20 cm in size) with a fine-grained matrix. This melange occasionally retains the original sedimentary structure that consists of pebbly mudstone with many angular blocks of chert, massive sandstone, and limestone. Chert blocks, several to tens of meters thick, are also included in this subcomplex and constitute light-brown to reddish-brown ribbon chert. Sandstone blocks are occasionally intercalated with millimeter-scale laminations. Limestone blocks several centimeters in diameter are found very infrequently in the study area.

Distribution : Nagasawa (Fig. 17) and the middle Ushibushisawa Valley (Fig. 15).

Main outcrops : Outcrops of sandstone and chert blocks in mudstone without shear structures are scattered in Nagasawarokkumi. Variegated pale-brown, dark-brown, white, and gray ribbon chert dominates the south I branch of the Nagasawagawa Valley. The eastern part of this chert block is faulted, striking N 16°W and dipping 80°W. The gouge of this fault attains a thickness of 2 m. Mudstone in the upper part of the south I branch of the Nagasawagawa Valley is sheared in a N 40°W trend with a vertical dip and contains a small amount of chert blocks. Limestone blocks are found infrequently in the mudstone matrix at one point in the valley.

Chert blocks and sandstone blocks in a mudstone matrix are widely distributed in the south II branch of the Nagasawagawa Valley (Fig. 17). Sandstone blocks in a shear matrix tend to be dominant in the lower part of the south II branch and where a single outcrop of limestone breccia in a mudstone matrix is found. Mixed rock is widely distributed in the north branch of the Nagasawagawa Valley (Fig. 17). Blocks range from several centimeters to 20 cm in diameter, and lens-shaped sandstone blocks are frequently found in this area in the structurally upper part of the Nagasawarokkumi Subcomplex. Slaty cleavage is rarely observed in this facies.

Chert slabs and lenses in a mudstone matrix are dominant in the south I branch of the Ushibushisawa Valley. Ribbon chert is observable adjacent to the western margin of the Miyako Pluton west of Nagasawarokkumi (Fig. 17). Elongated blocks in a sheared mudstone matrix are widely distributed in the western intervals from the outcrop of the ribbon chert, near Nagasawarokkumi.

Comparison : The Nagasawarokkumi Subcomplex is distinguished from the Komatsugura Subcomplex by the dominance of sandstone blocks.

Thickness : The Nagasawarokkumi Subcomplex attains a thickness greater than 100 m.

Contacts : The base of the Nagasawarokkumi Subcomplex is unknown because this complex occupies the lowest tectonostratigraphic unit in the Tanesashi Complex. The upper boundary of the Nagasawarokkumi Subcomplex with the Minamikawame Subcomplex is fault.

Fossils and age : No fossils have been found in the Nagasawarokkumi Subcomplex.

4.2.2. Minamikawame Subcomplex (new ; Mi)

Type locality : The lower part of the Minamikawame Valley, a branch of the Nagasawa River (Fig. 18).

Definition : Thick chert slab between the Nagasawarokkumi and Komatsugura Subcomplexes.

Lithology : The Minamikawame Subcomplex consists of medium gray or orange, and occasionally black and white striped, ribbon chert (Figs. 16b, 21b). This chert is overlain partly and conformably by siliceous mudstone and mudstone within the Minamikawame Subcomplex.

Distribution : The Minamikawame Subcomplex is patchily distributed in the eastern part of the southeastern Moichi area (Fig. 7).

Main outcrops : Large slabs of a variegated gray and purple ribbon chert are widely distributed in the Nagasawagawa (Fig. 17), Kitakawamesawa (Fig. 20a), and Minamikawamesawa valleys (Fig. 18). An overturned sequence starts from the ribbon chert, followed by siliceous mudstone, and mudstone near the upper end of the south I and II branches of the Nagasawagawa Valley (Fig. 17). Based on their distributions, this chert is an extension of the large chert slabs in the main valley of the Nagasawagawa Valley. The bedding of this large slab has a strike direction of N 10°W and dip of 44°W in the Nagasawagawa Valley, N 20°W and 30°W in the south I branch of the Nagasawagawa Valley, and N 35°W and 40°E in the north branch of the Nagasawagawa Valley. The strike and dip of the slab could not be measured at the outcrops, but it tilted shallowly to the west.

A 35-m thick mudstone is sandwiched between ribbon chert blocks of variegated white, black, brown, and purple color in the lower part of the Komatsugurasawa Valley (Fig. 19a). The mudstone is faulted with a strike of N 6°W and a dip of 40°W, while the base has a strike of N 16°W and a dip of 44°W.

Yellowish-brown, gray ribbon chert intercalated with millimeter-scale mudstone layers is widely distributed west to the vertical Komatsugura Fault (KOF in Fig. 19a) in the upper Komatsugurasawa Valley. This chert slab is an extension of the chert distributed in the Nagasawagawa Valley, and it decreases in thickness westwardly.

Many small outcrops of ribbon chert are widely distributed in the lower part of the north I branch of the Komatsugurasawa Valley (Fig. 19a). The mudstone faces on the left bank of the valley form a 10-m cliff but are only found in the lowest part of the right bank. Chert crops out in the middle and upper parts of the right bank. The chert cliff is 6–7 m in height. Ribbon chert crops out as cliffs 7–8 m in height in the lower north III branch of the Komatsugurasawa Valley (Fig. 19a).

Alternating beds of chert (each 1.5 cm thick) and mudstone (each 0.5 cm thick) show an imbricate structure in the north IV branch of the Komatsugurasawa Valley (Fig. 19a). Ribbon chert is observable as high cliffs, a few meters in height. The base of the chert is in fault contact with mixed rock on

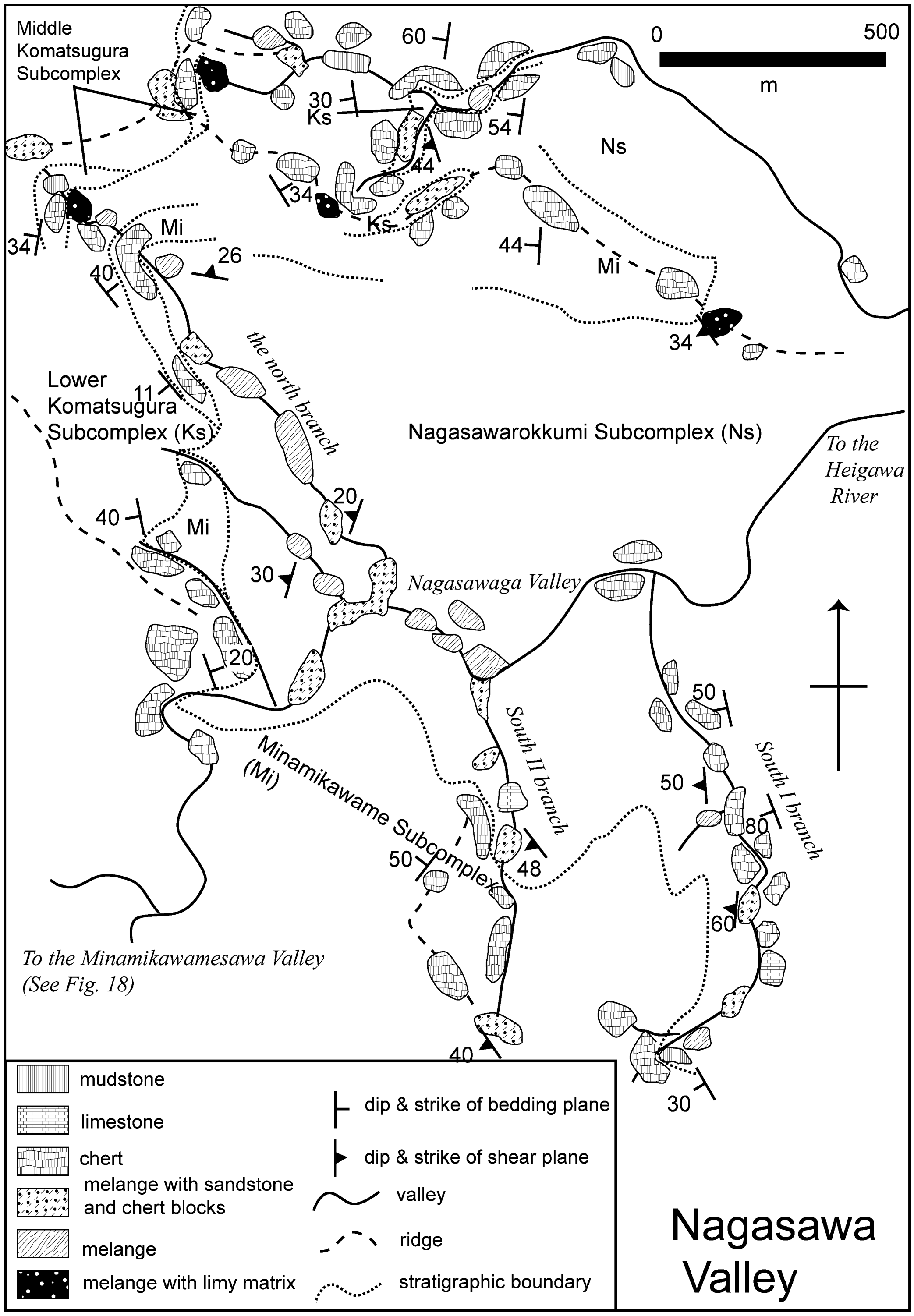


Figure 17. Field map showing the distribution of outcrops of the Nagasawarokkumi, Minamikawame, and Komatsugura Subcomplexes in the Nagasawagawa Valley.

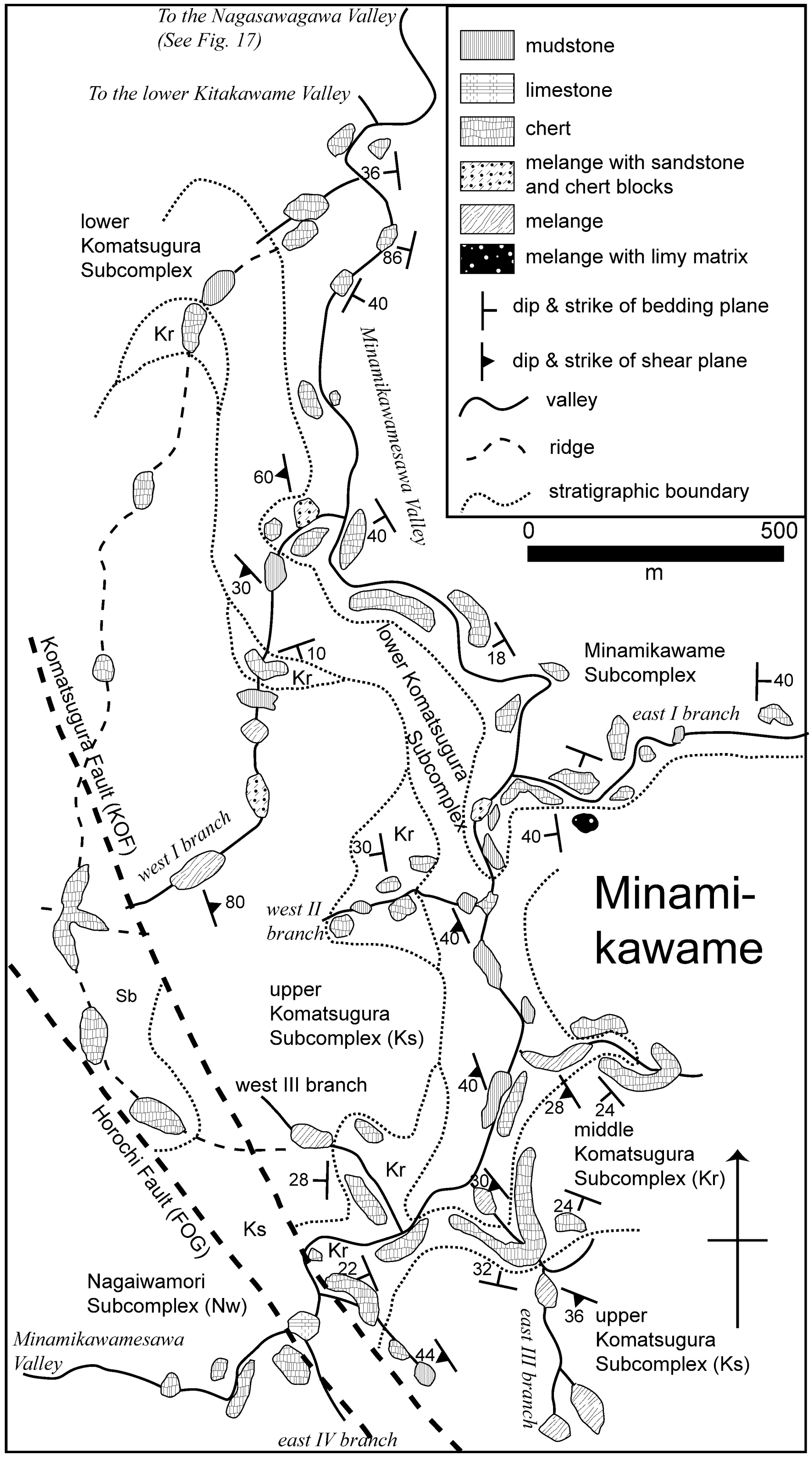


Figure 18. Field map showing the distribution of outcrops of the Minamikawame, Komatsugura, and Sambotoji Subcomplexes and boundaries of Komatsugura and Horochi faults.

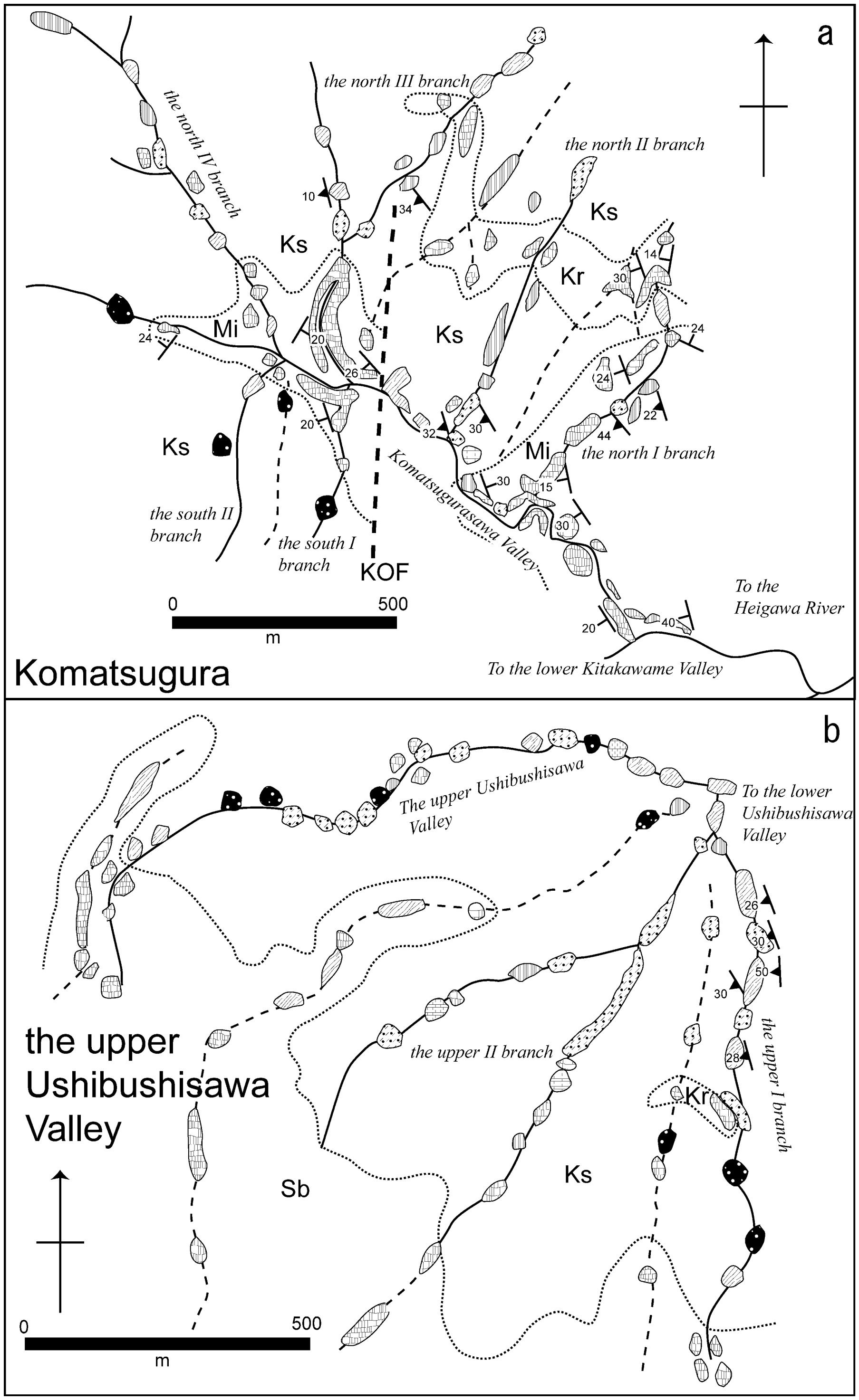


Figure 19. Field map showing the distribution of outcrops. (a) The Komatsugura Subcomplex (Ks : the lower and upper parts ; Kr : the middle part) and Minamikawame Subcomplex (Mi) in Komatsugura. (b) The Komatsugura and Sambotoji (Sb) Subcomplexes in the upper Ushibushi Valley.

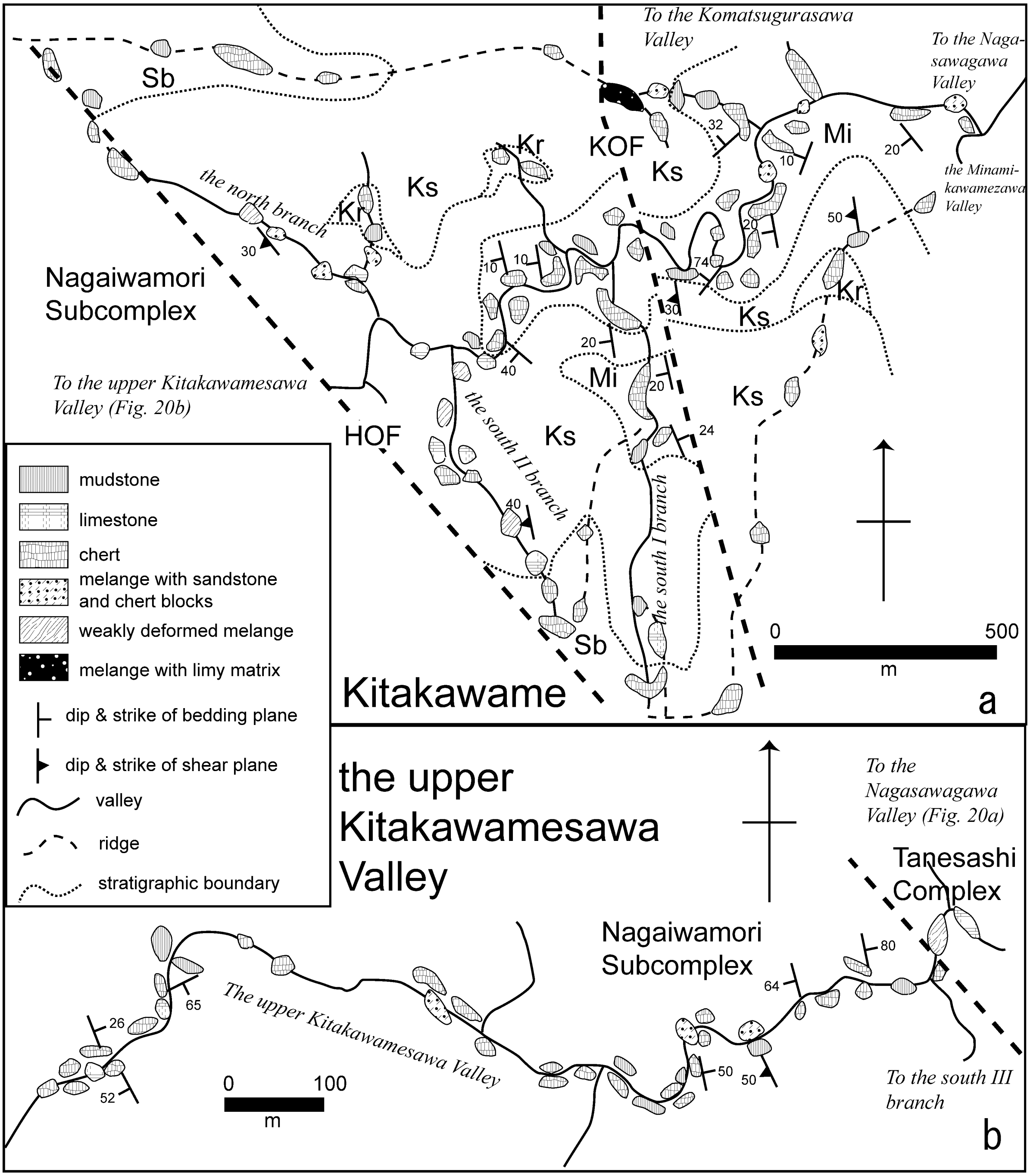


Figure 20. Field map showing the distribution of outcrops. (a) The Minamikawame (Mi), Komatsugura (Kr : the lower and upper parts ; Ks : the middle part), and the Sambotoji (Sb) Subcomplexes in Kitakawame. (b) The Tanesashi Complex to the east and Nagaiwamori Subcomplex to the west in the Kitakawamesawa Valley.

the riverbed of the Kitakawamesawa Valley (Fig. 20a). This fault, the Komatsugura Fault, strikes N 30°W and dips 30°W, and has consolidated gouge. A west-dipping chert-clastics sequence is recognized in the upper Kitakawamesawa Valley. This chert-clastics sequence lithologically changes into mudstone west of the upper Kitakawamesawa Valley. A vertical, north-trending fault extends to the Komatsugurasawa Valley (Fig. 17), and a chert-clastics sequence strikes N 25°W and dips 40°W in the uppermost Kitakawamesawa Valley. Each bed of dark-brown, gray, and black chert has a thickness of 2–5 cm. The Minamikawame Subcomplex along the south I branch of the Kitakawamesawa Valley (Fig.

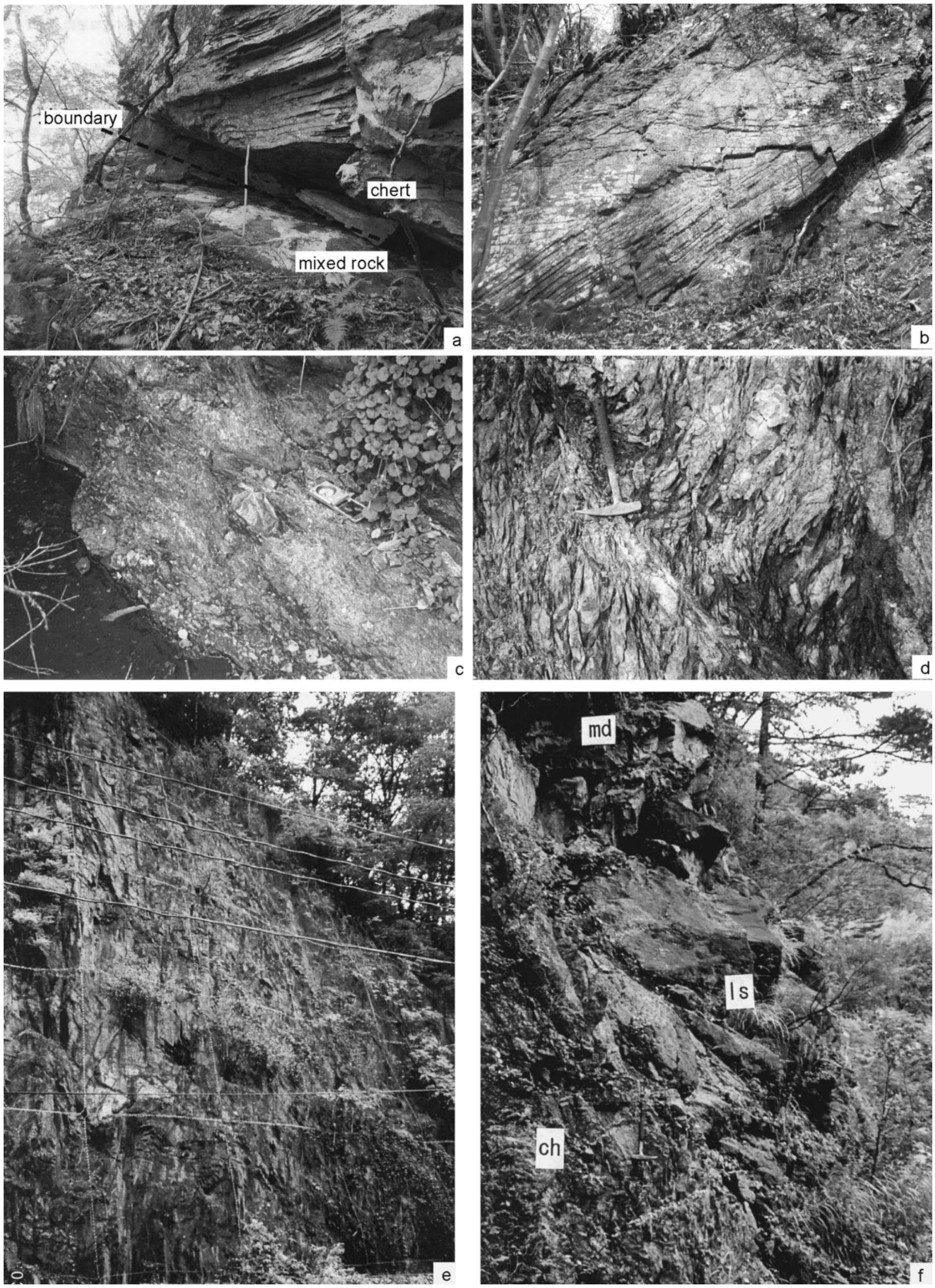


Figure 21. (a) The boundary between the lower Komatsugura (mixed rock) and the middle Komatsugura (chert) Subcomplexes in the east III branch of the Minamikawamesawa Valley. Scale bar=1 m. (b) Kink-folding ribbon chert of the middle Minamikawame Subcomplex in the II branch of the lower Ushibushisawa Valley. For scale, the length of the hammer handle is 30 cm. (c) Melange with chert and sandstone blocks of the Nagaiwamori Subcomplex in the Koshika'uchisawa Valley. For scale, the width of the clino-meter is 6.5 cm. (d) The boundary gouge zone between the Nagaiwamori and Kariya Subcomplexes (the Horochi Fault) in the ridge east of the Koshika'uchisawa Valley. The length of the hammer handle is 30 cm. (e) Ribbon chert of the Nagaiwamori Subcomplex along the Japan Railways (JR) Yamada Line. (f) Chert (ch), limestone (ls), and mudstone (md) blocks in the Nagaiwamori Subcomplex in the Kitsubushisawa Valley. The length of the hammer handle is 30 cm.

20a) has ribbon chert beds ; each bed is less than 5 cm thick.

Small outcrops of a variegated black, gray, white, and orange ribbon chert are scattered in the lower Minamikawamesawa Valley (Fig. 18), striking N 10°W, dipping 36°W, and upwardly changing into mudstone. Vertical cliffs (10 m high) of purplish-brown to white ribbon chert (each bed less than 5 cm thick) are found in the middle Minamikawamesawa Valley.

The alternating black and white ribbon cherts are exposed in the lower west I branch of the Minamikawamesawa Valley (Fig. 18). A variegated gray, brown, and white ribbon chert forms cliffs approximately 10-m high in the lower part of the east I branch of the Minamikawamesawa Valley (Fig. 18). This chert is in fault contact with the underlying mudstone with a strike of N 6°W and dip of 50°W.

Thickness : The Minamikawame Subcomplex reaches a maximum thickness of several to tens of meters.

Contacts : The Minamikawame Subcomplex is separated by faults from the Nagasawarokkumi and Komatsugura Subcomplexes.

Fossils and age : The Upper Triassic conodonts were recovered from the ribbon chert near the confluent point of the Ohkawa River with the Kitakawamegawa River, south of Nagasawa (Murai *et al.*, 1983).

4.2.3. Komatsugura Subcomplex (new ; Ks for the lower and upper parts and Kr for the middle part)

Type locality : The Ushibushi Valley (Fig. 15).

Definition : Mixed rock sandwiched between the Sambotoji and Minamikawame Subcomplexes, two significant chert horizons.

Lithology : This subcomplex is roughly subdivided into lower, middle, and upper parts based on tectonostratigraphic positions. The lower Komatsugura Subcomplex contains blocks of mudstone, sandstone, chert, and a small amount of limestone and basalt blocks in a mudstone matrix (Figs. 16c, 16d, 16e, 16h). The middle part of the Komatsugura Subcomplex (Fig. 21a) consists of gray, reddish-brown, purple, and black ribbon chert, and reaches a thickness of several meters. The upper Komatsugura Subcomplex (Figs. 16f, 16g) is lithologically similar to the lower Komatsugura Subcomplex, but limestone blocks are relatively dominant in this part. Therefore, we propose formal subdivisions in the Komatsugura Subcomplex, based on this structural variation.

Limestones yielding Middle Permian fusulinids in the upper Komatsugura Subcomplex presented as granular-pebbly blocks and as a few large blocks in a hemipelagic mudstone matrix, associated with basaltic blocks. These blocks are concentrated in mudstone without shear structures.

Distribution : The Komatsugura Subcomplex is widely distributed in elevations ranging from 200 to 400 m in the southeastern Moichi area (Fig. 7). The chert slab of the middle Komatsugura Subcomplex is thin but traceable in the southeast Moichi area, although it is indistinguishable in the northern part of the southeastern Moichi area.

Main outcrops : Small chert blocks in a mudstone matrix are dominant in southeastern intervals from the mouth of the Ushibushisawa Valley (Fig. 15). This mudstone occasionally includes sandstone blocks approximately 1 m in size. A N 36°W striking and 64°W dipping fault shears this mudstone with gouge that is 40 cm thick. Mudstone and chert blocks in a mudstone matrix are exposed in the middle Ushibushisawa Valley (Fig. 15). These blocks are angular in shape and are randomly scattered in the matrix. Weakly bedded sandy mudstone is intercalated sporadically in this mudstone matrix. The bedding of these reddish brown chert blocks strikes N 18°W and dips 20°W. Another chert body (2 m thick × 10 m wide) exposed in the upper Ushibushi Valley is oriented 30- to the west, which is parallel to the dips of the shear planes (Fig. 15).

Small, subrounded limestone-bearing conglomerates several to tens of centimeters thick are interbedded in mudstone in the upper Ushibushisawa Valley (Fig. 15). Chert blocks in the mudstone matrix are observable in the upper Ushibushisawa Valley. East to this chert block, abundant limestone blocks, rare chert blocks, and very rare mudstone blocks are included in calcareous sandy mudstone. The shear plane of this mudstone strikes N 40°W and dips approximately 50°W, so that this mudstone probably creates an antiform structure.

Many lens-shaped and irregularly shaped ribbon chert blocks, several to tens of centimeters in diameter, and rare sandstone blocks, are commonly found in the mudstone matrix along the I branch of the Ushibushisawa Valley (Fig. 19b). This mudstone develops N 15°W-striking and 35°W-dipping shear planes. West to the mudstone, a large ribbon chert slab is widely distributed, and limestone blocks in the mudstone matrix are rarely observed. Other limestone blocks in a mudstone matrix are visible at the upper end of the Ushibushisawa Valley I branch. Mudstone with abundant sandstone blocks and rare, lens-shaped chert blocks are distributed in the II branch of the Ushibushisawa Valley. Outcrops of limestone are found near the upper end of the II branch. These limestone blocks are not associated with a mudstone matrix.

Chert blocks in a mudstone matrix are weakly sheared by N 20°W-trending and 50°W-dipping shear planes in the upper end of the south I and II branches of the Ushibushisawa Valley. The slaty cleavage has a strike of N 20°W and dip of 50°W. Limestone blocks in the mudstone matrix are found in the upper end of the south II branch of the Ushibushisawa Valley. A large outcrop of kink ribbon chert associated with axial-plane cleavages is found in the south II branch of the Ushibushisawa Valley. The strike and dip of the axial planes of the kink fold are N 44°W and 30°W. Chert blocks become dominant between the south I and II branches of the Ushibushisawa Valley. This chert is in sharp contact with the underlying mixed rock by a fault with consolidated fault gouge. This fault steeply tilts southward. Sandstone blocks and chert blocks approximately 1 cm in size are found in sheared mudstone near the summit of Mount Unedoriyama. This facies belongs to the lower Komatsugura Subcomplex. The mixed rock of the lower Komatsugura Subcomplex is in sharp contact with the underlying Minamikawame Subcomplex by a fault with a 60-cm-thick gouge zone in the Komatsugurasawa Valley (Fig. 19a). Limestone blocks are scattered in mudstone in small branches of the Komatsugurasawa Valley. This mixed rock is in contact with the Minamikawame Subcomplex by a vertical fault (the Komatsugura Fault, KOF, in Fig. 19a) in the upper Komatsugurasawa Valley.

Sedimentary breccias contain chert, limestone, and basaltic clasts with the absence of mudstone in the lower north branch of the Komatsugurasawa Valley, whereas only chert blocks are found in mudstone in the upper north branch of the Komatsugurasawa Valley. These facies are the lower Komatsugura Subcomplex. The size of each block ranges in thickness from a few centimeters to several meters. Chert blocks and sandstone blocks are contained in the sheared black mudstone in the lower south branch of the Komatsugurasawa Valley, whereas blocks are found in mudstone in the upper part of the south branch of the Komatsugurasawa Valley. Relatively large ribbon chert blocks several meters in size are found in the mudstone matrix in the upper north I branch of the Komatsugurasawa Valley (Fig. 19a). This mixed rock is the lower Komatsugura Subcomplex.

Ribbon chert blocks ranging from 20 cm to several meters in the mudstone matrix are widely distributed in the north II branch of the Komatsugurasawa Valley (Fig. 19a). Mudstone develops N 30°W striking and 20°W dipping slaty cleavages. Massive mudstone is found in the upper north II branch of the Komatsugurasawa Valley. The chert of the middle Komatsugura Subcomplex is exposed near the upper end of the north II branch of the Komatsugurasawa Valley and adjacent slopes and in the north I and III branches of the Komatsugurasawa Valley. Chert blocks embedded in authigentic biotite-bearing mudstone of the upper Komatsugura Subcomplex crop out rarely in the upper end of the north II branch of the Komatsugurasawa Valley.

Chert lenses are found in sheared mudstone in the north III branch of the Komatsugurasawa Valley, which is the lower Komatsugura Subcomplex (Fig. 19a). A large chert correlated with the middle Komatsugura Subcomplex is shallowly tilted to the north in the upper north III branch of the Komatsugurasawa Valley and is also found in the north II branch of the Komatsugurasawa Valley. The upper Komatsugura Subcomplex in the north III branch of the Komatsugurasawa Valley consists of sandstone blocks in a matrix and sheared mudstone with chert and sandstone blocks. The shear plane of the mudstone has a strike of N 50°W and dip of 30°W. Mudstone in the north IV branch of the Komatsugurasawa Valley contains relatively large sandstone blocks (ca. 0.5-1.0 m long) and abundant small chert blocks (a few centimeters long).

West to the north-trending vertical fault in the Komatsugurasawa Valley, small outcrops of mudstone of the lower Komatsugura Subcomplex are scattered in the upper end of the north IV branch of the Komatsugurasawa Valley. Few outcrops of limestone-bearing mixed rock are found in the upper south I branch of the Komatsugurasawa Valley. This mixed rock is marked in the upper south II branch of the Komatsugurasawa Valley, where the mudstone contains medium- to coarse-grained sandstone blocks in a shear matrix. Mixed rock correlating to the lower Komatsugura Subcomplex contains limestone blocks several to tens of meters in size and rare chert blocks in the upper end of the Kitakawamesawa Valley.

Limestone blocks ranging from 10 cm to 2 m are found in a black mudstone matrix in the lower to middle north branch of the Kitakawamesawa Valley (Fig. 20a). Microscopy reveals that this mudstone matrix also contains chert and sandstone clasts. This facies is correlated with the lower Komatsugura Subcomplex. Ribbon chert of the middle Komatsugura Subcomplex is widely distributed in the upper north branch of the Kitakawamesawa Valley. Small outcrops of limestone of the lower Komatsugura Subcomplex and the overlying ribbon chert of the middle Komatsugura Subcomplex are scattered near the upper south I branch of the Kitakawamesawa Valley.

Limestone and basalt blocks in the siliciclastic matrix of the lower Komatsugura Subcomplex are found in the lower south II branch of the Kitakawamesawa Valley (Fig. 20a). Limestone blocks are rounded and range from several meters to 20 m in size. Ribbon chert and associated siliceous mudstone of the middle Komatsugura Subcomplex crop out near the upper end of the south II branch of the Kitakawamesawa Valley and adjacent ridge.

Chert and mudstone blocks in the sheared mudstone matrix of the lower Komatsugura Subcomplex are widely distributed in the middle Minamikawamesawa Valley (Fig. 18). The strike and dip of the shear plane are N 30°W and 40°W. Variegated gray, black, and purplish-brown ribbon chert forms a 5-m high cliff in the middle part of the Minamikawamesawa Valley. This chert belongs to the middle Komatsugura Subcomplex. Limestone blocks of the upper Komatsugura Subcomplex are in fault contact with the middle Komatsugura Subcomplex in the middle Minamikawamesawa Valley.

An apparently 5-m-thick mudstone overlies ribbon chert of the middle Komatsugura Subcomplex in the middle part of the west I branch of the Minamikawamesawa Valley (Fig. 18). Limestone blocks in the mudstone matrix of the upper Komatsugura Subcomplex are found near the upper end of the west I branch of the Minamikawamesawa Valley and an adjacent ridge. Limestone blocks with the mudstone matrix crop out near the mouth of the east I branch of the Minamikawamesawa Valley, which is probably correlated with the lower Komatsugura Subcomplex.

A large chert body associated with slaty cleavage-developed mudstone of the middle Komatsugura Subcomplex crops out in the lower west II branch of the Minamikawamesawa Valley (Fig. 18) and is in fault contact with mudstone having a strike of N 30°W and dip of 40°W. Tall, narrow cliffs of ribbon chert of the middle Komatsugura Subcomplex are located in the lower west II branch of the Minamikawamesawa Valley. Slaty cleavage-developed mudstone is widely distributed in the lower to middle part of the west II branch of the Minamikawamesawa Valley, where cleavage strikes are N 50°W and dips are 12°W. A chert block several tens of meters in height is found in the upper west II branch of the Minamikawamesawa Valley. Mixed rock with large carbonate blocks that are correlated with the middle Komatsugura Subcomplex are also distributed in the upper end of this branch.

Pebbly mudstone of the lower Komatsugura Subcomplex is in sharp contact with ribbon chert of the middle Komatsugura Subcomplex, in the middle of the east II branch of the Minamikawamesawa Valley. The pebbly mudstone is continuously observable near the mouth of the east III branch of the Minamikawamesawa Valley. Ribbon chert of the middle Komatsugura Subcomplex is widely distributed in the lower part of the east III branch of the Minamikawamesawa Valley. Another chert body of the middle Komatsugura Subcomplex can be seen on the northern slope of a small valley and extends east from the east III branch of the Minamikawamesawa Valley. Pebbly mudstone of the upper Komatsugura Subcomplex crops out in a small southern valley of the east III branch of the Minamikawamesawa Valley. The strike and dip of the slaty cleavage of the pebbly mudstone are N 64°W and 36°W.

A thin slab of ribbon chert of the middle Komatsugura Subcomplex is found on the right bank of the west III branch of the Minamikawamesawa Valley (Fig. 18), whereas porphyrite dike sheets feed to the ribbon chert on the left bank in the same valley. Pebbly mudstone of the upper Komatsugura Subcomplex is located structurally above this ribbon chert in the middle of the west III branch of the Minamikawamesawa Valley. There are no outcrops, but mixed rock with large carbonate blocks is scattered in the upper reaches of this valley. White to gray ribbon chert (3–5 cm beddings) is strongly folded in the lower east IV branch of the Minamikawamesawa Valley. The fold axis has a trend of N 44°W. A significant fault with a gouge zone 1–3 m thick strikes N 44°W and has a vertical dip in the middle of the east IV branch of the Minamikawamesawa Valley (Fig. 18). Cleavage-bearing mudstone is widely distributed in the middle to upper parts of the Minamikawamesawa Valley.

Pebbly mudstone of the Komatsugura Subcomplex crops out near the upper end of the Tokakemesawa Valley and is continuously observed in the upper reaches of the Yamadabatasawa Valley (Fig. 23). Massive mudstone, highly weathering sandstone, and a small block of ribbon chert crop out near the end of the Yamadabatasawa Valley.

Thickness : The Komatsugura Subcomplex reaches a maximum thickness of 500 m.

Contacts : The chert of the middle Komatsugura Subcomplex is in fault contact with the lower Komatsugura Subcomplex. The precise nature of the contact between the middle and upper parts of the Komatsugura Subcomplex has not yet been determined, but fault contact is probable.

Fossils and age : Limestone blocks in the upper Komatsugura Subcomplex yield Middle Permian fusulinids including *Parafusulina* sp., *Pseudodoliolina* cf. *ozawai* Yabe et Hanzawa, and *Neoschwagerina margaritae* Deprat (Choi, 1972 ; Onuki, 1956 ; Onuki and Kudo, 1954 ; Tazawa *et al.*, 1997 ; Yoshida and Katada, 1964).

Comparison : The Komatsugura Subcomplex is distinguishable from the Nagasawarokkumi Subcomplex only by its tectonostratigraphic position.

4.2.4. Sambotoji Subcomplex (new ; Sb)

Type locality : nearly the peak of Mount Sambotoji (Fig. 19).

Definition : This subcomplex is defined by thick, white ribbon chert that structurally overlies the mudstone of the uppermost part of the Tanesashi Complex in the southeastern Moichi area (Fig. 7).

Lithology : Thick, white ribbon chert horizon and the overlying massive mudstone.

Distribution : The Sambotoji Subcomplex is located in the southeastern Moichi area on mountain peaks at elevations higher than 400 m.

Main outcrops : Ribbon chert is dominant near the upper end of the Ushibushisawa Valley (Fig. 15) and continues to the upper end of the Kitakawamesawa Valley and the upper end of the II branch of the Ushibushisawa Valley (Fig. 19). White, opaque ribbon chert is found near the end of the I branch of the Ushibushisawa Valley.

Thickness : Several to tens of meters.

Contacts : The base of the Sambotoji Subcomplex is in fault contact with the Komatsugura Subcomplex. The top of the Sambotoji Subcomplex is unknown because the topmost subcomplex has been eroded.

Fossils and ages : No fossils have been found in the Sambotoji Subcomplex.

4.3. Kitakawame Complex (new)

4.3.1. Nagaiwamori Subcomplex (new ; Nw)

Type locality : Along a unpaved road and the riverside, between the confluence of the I branch of the Toyomanegawa River with the Toyomanegawa River (Fig. 22).

Definition : A repetition of chert-clastics sequences with limestones.

Distribution : The Nagaiwamori Subcomplex is distributed in a NNW trend from the Toyomane-Kazawa area (Fig. 6) to northwestern Moichi (Fig. 7).

Lithology : This subcomplex is characterized by a repetition of chert-clastics sequences that are composed mainly of ribbon cherts and the overlying clastic rocks. Faults having gouge zones a few meters in thickness separate the base of the chert-clastics sequences from the underlying chert-clastics sequences. Although the overall sequences are substantially deformed by faults and mesoscopic folds, individual strata can be traced laterally for as much as several kilometers (Figs. 6, 7). The subcomplex is generally deformed by northwest-trending tight macroscopic folds, with a half-wavelength of 200–500 m (Fig. 9), as well as mesoscopic intrafolial folds.

Ribbon chert of each chert-clastics sequence is composed of variegated purplish-brown, brown, dark-brown, white, dark-gray, and purple ribbon chert (2–5 cm bedding ; Fig. 21e). Intercalated muddy films are mostly absent. Most chert-clastics sequences start from ribbon chert and are followed by bluish-dark-gray, gray siliceous mudstone, and dark-gray massive mudstone. Siliceous mudstone is composed of clay with a few silt grains. Mudstone is occasionally laminated with silty to fine-grained sandstone layers. Mudstone is overlain with light-gray, fine- to medium-grained sandstone, or alternating sandstone and mudstone. Sandstone is dominated by feldspathic wacke. A melange, but not a typical one, is occasionally observable with chert, siliceous mudstone, and sandstone blocks in shear black mudstone (Fig. 21c). Limestone breccias with a minor amount of blocks of ribbon chert and greenstone are infrequently found in the Nagaiwamori Subcomplex (Fig. 21f). The matrix of this limestone breccia consists only of mud, and lacks siliciclastic grains.

Main outcrops: White to dark-gray, recrystallized, massive or ribbon chert crops out at the confluence of the Kogawa Valley and Taguri Valley and at the confluence of the Kogawa Valley and Okudaira Valley. Ribbon chert, bedded siliceous mudstone, millimeter-scale parallel-laminated mudstone, and melange strike N 2°W-18°W and dip 20°-63°W in the I branch of the Toyomanegawa River (Fig. 22). White to dark-gray ribbon chert in the Toyomanegawa Valley west of the Hinodo Valley lacks mudstone films between each chert bed. A gradual upward lithological change from chert to mudstone is observable along a roadside in the Hinodo Valley.

A repeated sequence of chert, siliceous mudstone, and mudstone widely crops out in Ohkawa. Ribbon chert and an overlying dark-brown siliceous mudstone crops out in 550-m intervals west of the mouth of the Taguri Valley. Sandstone, mudstone, and white to gray, recrystallized ribbon chert are exposed in the upper Taguri Valley.

Chocolate-colored, brown, white, gray, and purple ribbon chert (2-5 cm bedding) is observed in the middle Kitakawamesawa Valley (Fig. 20b) and is in sharp contact with the mudstone by a N 20°W-trending and vertically dipping fault and a N 30°W-trending and 60°W-dipping fault associated with a gouge zone that is 1.5-m thick. West to this fault gouge zone, dominant ribbon chert and rare mixed rock are distributed in this valley. Limestone breccia associated with dark-brown, purple, white, and gray ribbon chert blocks and green volcanic and volcaniclastic rock blocks are scattered in the upper middle part of the Kitakawamesawa Valley.

Thermal-metamorphosed massive chert is widely distributed in the south III branch of the Kitakawamesawa Valley. Brown, white, dark-brown, and black ribbon chert (2-8 cm bedding) and intercalated millimeter-scale mudstone films are exposed in the Tokakemesawa Valley (Fig. 23). Massive mudstone is distributed in the lower Yamadabatasawa Valley (Fig. 23), and ribbon chert is found in the middle to upper reaches of this valley.

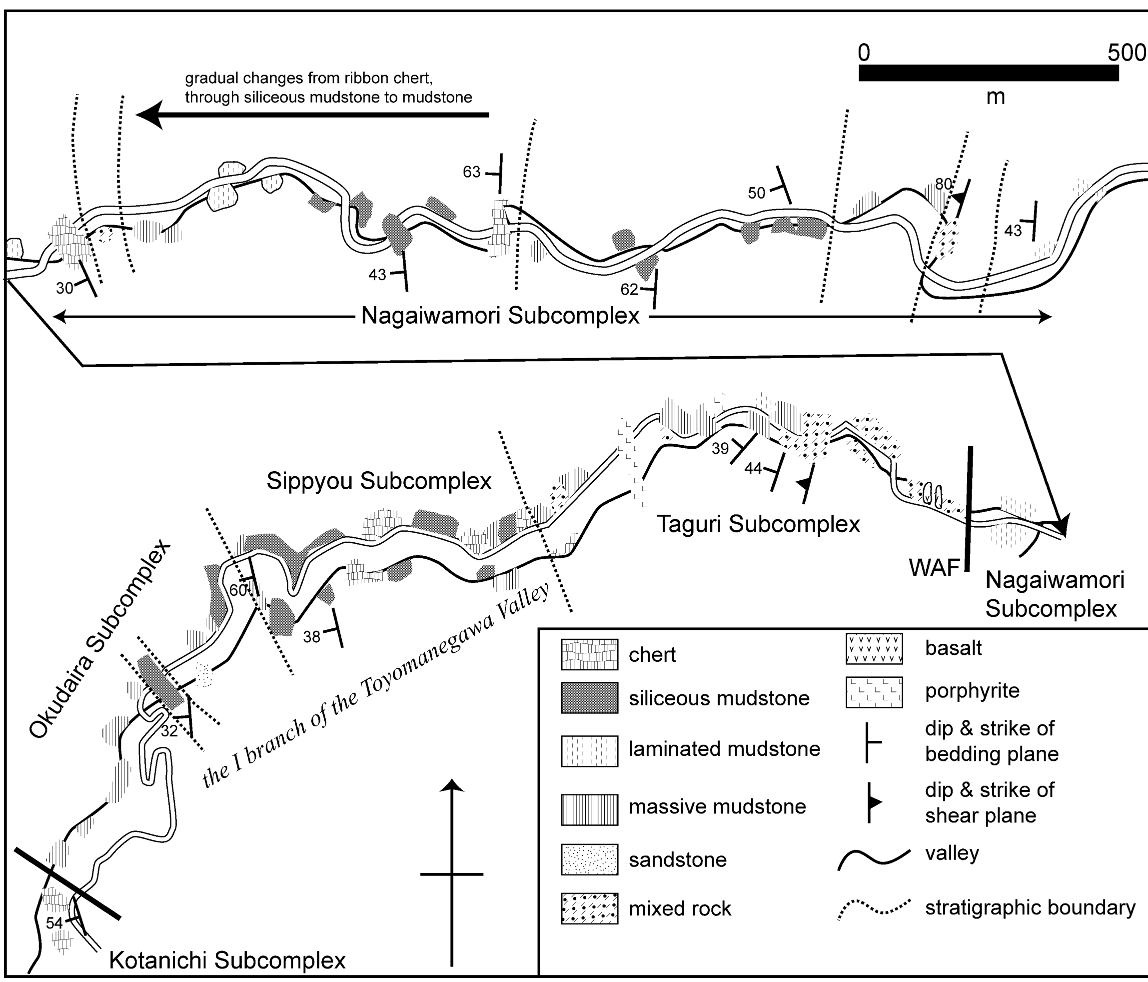


Figure 22. Field map showing the distribution of outcrops of the Nagaiwamori, Taguri, Sippyou, Okudaira, and Kotanichi Subcomplexes along the I branch of the Toyomanegawa Valley.

A NNW-striking, vertical-dipping, gray and brown ribbon chert crops out in the upper 200-m interval from the mouth of the Koshika'uchisawa Valley. Mudstone with sandstone and chert blocks is distributed in the middle to upper Koshika'uchisawa Valley. Gray, brown, red ribbon chert crops out in the lower Koshika'uchisawa Valley. This chert is in fault contact with black massive mudstone at elevations of approximately 130 m. The fault gouge is less than 1 m thick. Massive black mudstone lies west of the fault in the valley. Boulders of crinoid-bearing limestone are scattered on the left bank of the Koshika'uchisawa Valley ; we could not find any outcrops.

Light-green ribbon chert is exposed at 200 m elevation in the small valleys facing the slope east of Uenodai ; gray ribbon chert is found at elevations higher than 200 m to the west. This chert generally strikes NW-SE, dips to the northeast, and lithologically changes into siliceous mudstone and mudstone to the west. Gray to red ribbon chert dominates on the left bank of the Kakunosawa Valley ; this chert continues in a southeast trend into a southern-trending ridge between the Kakunosawa and Shikauchisawa valleys. Gray ribbon chert is dominant at elevations higher than 500 m to the southwest in the Takinosawa Valley (Fig. 13). This ribbon chert changes into mudstone. The strikes and dips of this chert are significantly variable. Gray ribbon chert associated with black mudstone is widely distributed at elevations higher than 450 m in the Yakatagawasawa Valley. The strike and dip of the bedding of this chert vary from N 10° E to N 70°W and from 50°S to 75°S.

Gray chert of variable strike and dip is exposed from 2 km west of the mouth of the Kuranosawa Valley. Gray ribbon chert, mudstone, and white to gray limestone breccia crop out in the Kitsubushisawa Valley. Limestone breccia consisting of white to gray limestone in a dark-green volcaniclastic matrix is in fault contact with ribbon chert and mudstone. Ribbon chert is observed in the lower O'shounaisawa Valley, and black massive mudstone, boulder stone of intrusive rocks, and mudstone are found in the

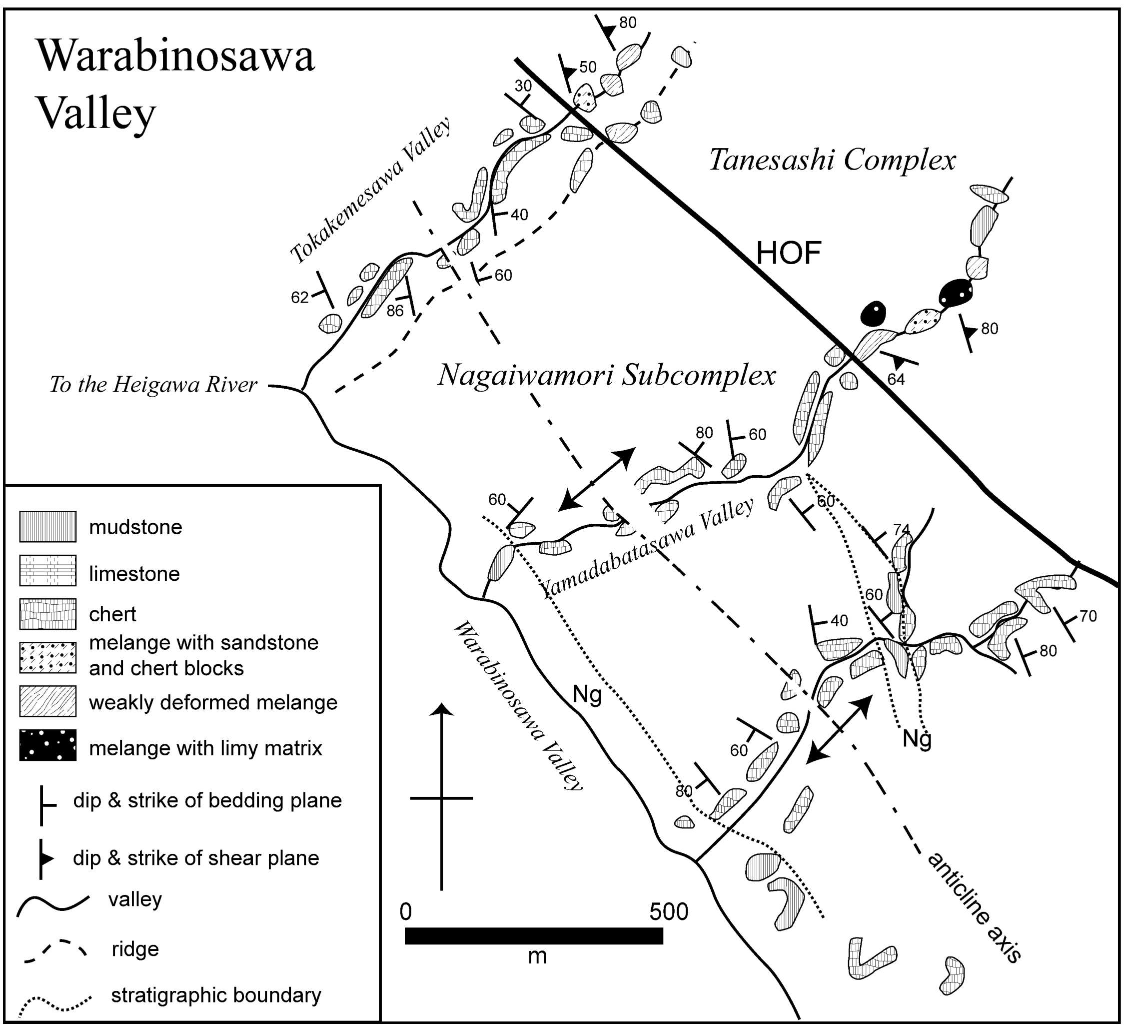


Figure 23. Field map showing the distribution of outcrops of the Tanesashi Complex and the Nagaiwamori Subcomplex on the northeastern slope of the Warabinosawa Valley.

middle to upper O'shounaisawa Valley.

Thickness : The Nagaiwamori Subcomplex exceeds an apparent thickness of 2000 m.

Contacts : Both boundaries of the Nagaiwamori Subcomplex are faulted. The eastern boundary of the Nagaiwamori Subcomplex in the northwest Moichi area is observable on the ridge between the Shoudonosawa and Koshika'uchisawa valleys, where the Nagaiwamori Subcomplex is in fault contact with the Kariya Subcomplex of the Moichi Complex, associated with a 100-m gauge zone. The western boundary of the Nagaiwamori Subcomplex in the northwest Moichi area crops out close to the joint point of the Nawauchisawa and Kuranosawa valleys.

Fossils and age : Probable Paleozoic crinoid stems are scattered in boulder stone of limestone on the left bank of the Koshika'uchisawa Valley. Otherwise, no fossils have been recovered from this subcomplex.

4.3.2. Shimochi Subcomplex (new ; Sm)

Type locality : In the Shimochizawa Valley (Fig. 24).

Definition : Ribbon chert with breccia bearing limestone-basalt.

Lithology : The Shimochi Subcomplex is dominated by ribbon chert, but is also marked by the presence of limestone-bearing breccia with Mesozoic scleractinian corals (Ehiro *et al.*, 2001). This breccia also contains clasts of chert, siliceous mudstone, and volcaniclastic rocks with a limy matrix (Figs. 26a, 26b) and is further characterized by upward-fining sediments (30-50 m at total thickness) with laminations and containing pebbly to sandy grains. No terrigenous matter is found in the matrix of this breccia. Clasts of siliceous mudstone are irregular in shape, show soft sediment deformation, and contain radiolarian remains. Chert clast is bedded, angular in shape, and light-gray to dark-gray in color. These clasts yield abundant radiolarians of unknown age, as well as Triassic conodonts. Volcanic rocks are gray to pale-green clinopyroxene-olivine basalt with inequigranular textures. Hyaloclastite clasts are also found in this breccia. The lithology, except for that of the limestone-bearing breccia, is similar to the lithology of the Nagaiwamori Subcomplex.

Distribution : The Shimochi Subcomplex has a limited distribution in the western Toyomane-Kazawa area and thins out southwardly and northwardly (Fig. 7).

Main outcrops : Fining-grading limestone breccia crops out on the western slope of the Shimochizawa Valley (Fig. 24) and is associated with blocks of limestone, chert, and volcanic rocks. These limestone blocks range from several millimeters to 40 cm in diameter. The strike and dip of the bedding of fining-grading limestone breccia are N 34°W and 60°W, respectively, at elevations around 280 m at the southwestern slope near a branch of Nishikawame Elementary School. White chert crops out around the outcrops of limestone breccia, but the relationships between chert and breccia are unknown. Limestone breccia with a minor amount of chert breccia is observable at 385 m elevation on the ridge east of the Matachisawa Valley. This breccia is also found on the ridge between the Matachisawa and Kurihosawa valleys.

Thickness : A thickness of 430 m in the Ohkawa Valley and 200 m in the Shimochi and Nagasawa valleys.

Contacts : Both contacts are probably faulted.

Fossils and age : Limestone clasts in breccia yield Mesozoic scleractinian corals (Ehiro *et al.*, 2001). Chert blocks below the limestone-bearing breccia contain early Middle Triassic conodonts (*Cornudina breviramulis* [Tatge] with two denticles on the anterior process) and radiolarians (*Archaeosemantis cristianensis* Dumitrica ; Ehiro *et al.*, 2001).

Comparison : The Shimochi Subcomplex is similar to the chert-clastics sequence of the Nagaiwamori Subcomplex but differs from the latter by the presence of limestone breccias bearing Mesozoic scleractinian coral.

4.4. Tsugaruishi Complex (new)

4.4.1. Taguri Subcomplex (new ; Tg)

Type locality : At elevations ranging from 270 to 300 m in the Taguri Valley.

Definition : Melange with blocks of chert, siliceous mudstone, and sandstone.

Lithology : The Taguri Subcomplex consists of mixed rock having chert, siliceous mudstone, and sandstone blocks with a muddy matrix (Fig. 26c). This subcomplex is occasionally dominated by blocks of light-gray, hyaloclastite, aphyric basalt, clinopyroxene basalt, and olivine-augite basalt. Sandstone and chert blocks become dominant in the northern extension of the subcomplex.

Distribution : The Taguri Subcomplex adjoins to the west of the Shimochi or Nagaiwamori Subcomplexes and is distributed in a NNW-SSE trend in the Toyomane-Kazawa area (Figs. 6, 7).

Main outcrops : Melange facies near the joint point of the Kurihora and Ohkawa valleys yield chert, siliceous mudstone, and sandstone blocks in sheared black mudstone. The strike and dip of the shear planes are N 27°W and 60-70°W. Blocks of volcanic rocks are exposed in the western margin of the Taguri Subcomplex at this point. Melange adjoining the chert of the Shimochi Subcomplex in the Shimochizawa Valley contains blocks of light-gray to pale-green volcanic rocks, chert, and siliceous mudstone. Melanges around 300 m elevation in the Tagurisawa Valley contain blocks of mudstone, sandstone, chert, and basaltic rocks. These blocks are elongated in a northwestern trend. Small outcrops of hyaloclastite, aphyric basalt, and olivine-augite basalt are scattered in the Toyomanegawa Valley (Fig. 25). These volcanic rocks are probably blocks in melanges. Small blocks (ca. 20 cm thick) of sandstone and chert are present in melanges in the I branch of the Toyomanegawa Valley (Fig. 22). The melange with blocks of chert and siliceous mudstone ($<$50 cm thick) is characterized by well-developed shear planes. The shear plane strikes N 13°W and dips 60°-70°W in the upper 100-m interval of the Sippyouzawa Valley from the meeting point with the Toyomanegawa Valley. Immediately adjacent to the melange, mudstone that is 3-m thick and gray to light-gray volcanic rocks occur in the Sippyouzawa Valley. The strike and dip of the bedding of the mudstone are N 27°E and 60° W in this valley.

Thickness : 130-390 m.

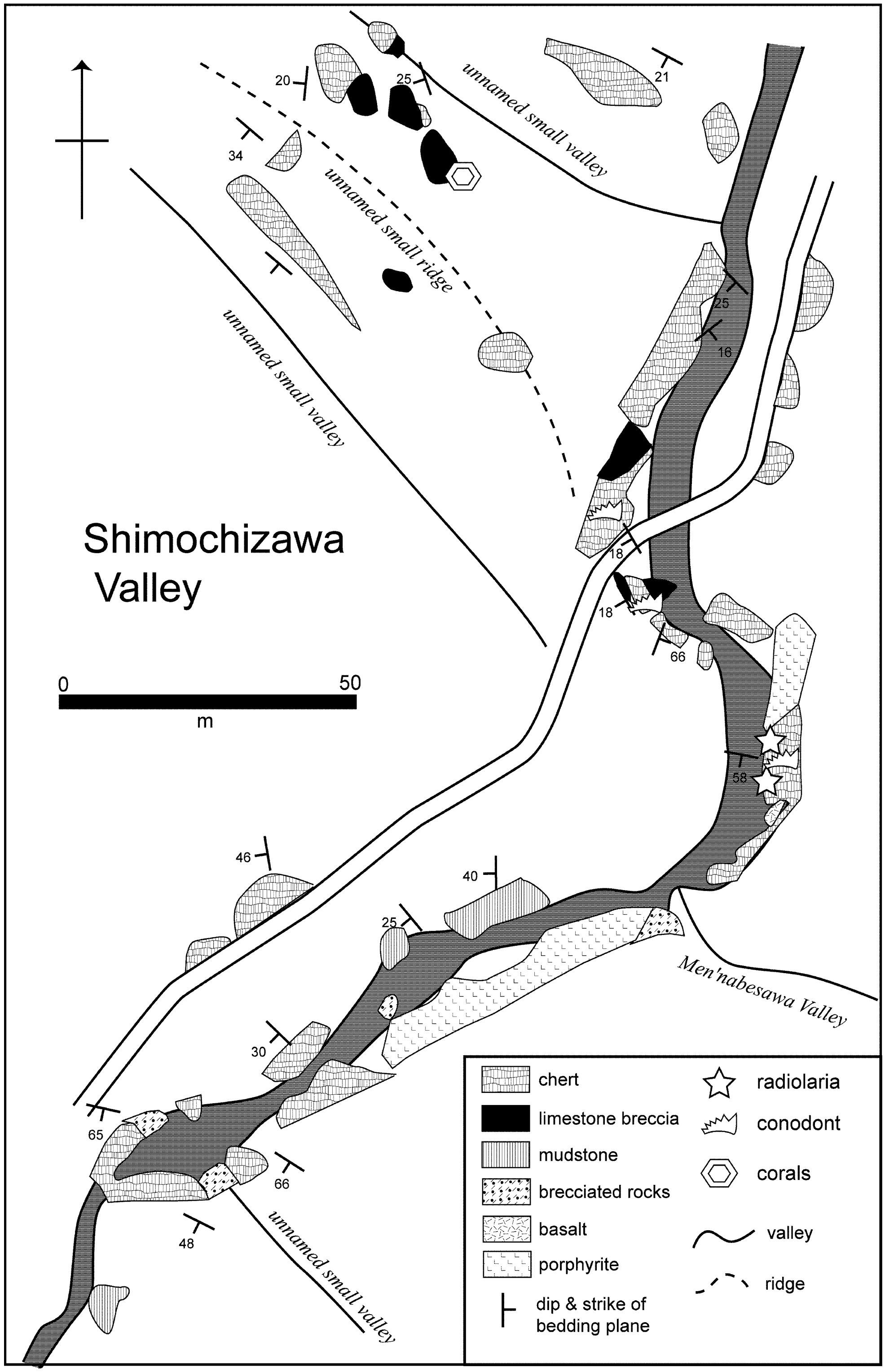


Figure 24. Field map showing the distribution of outcrops of Mesozoic limestone, chert, and siliceous mudstone blocks of the Shimochi Subcomplex in the Shimochizawa Valley.

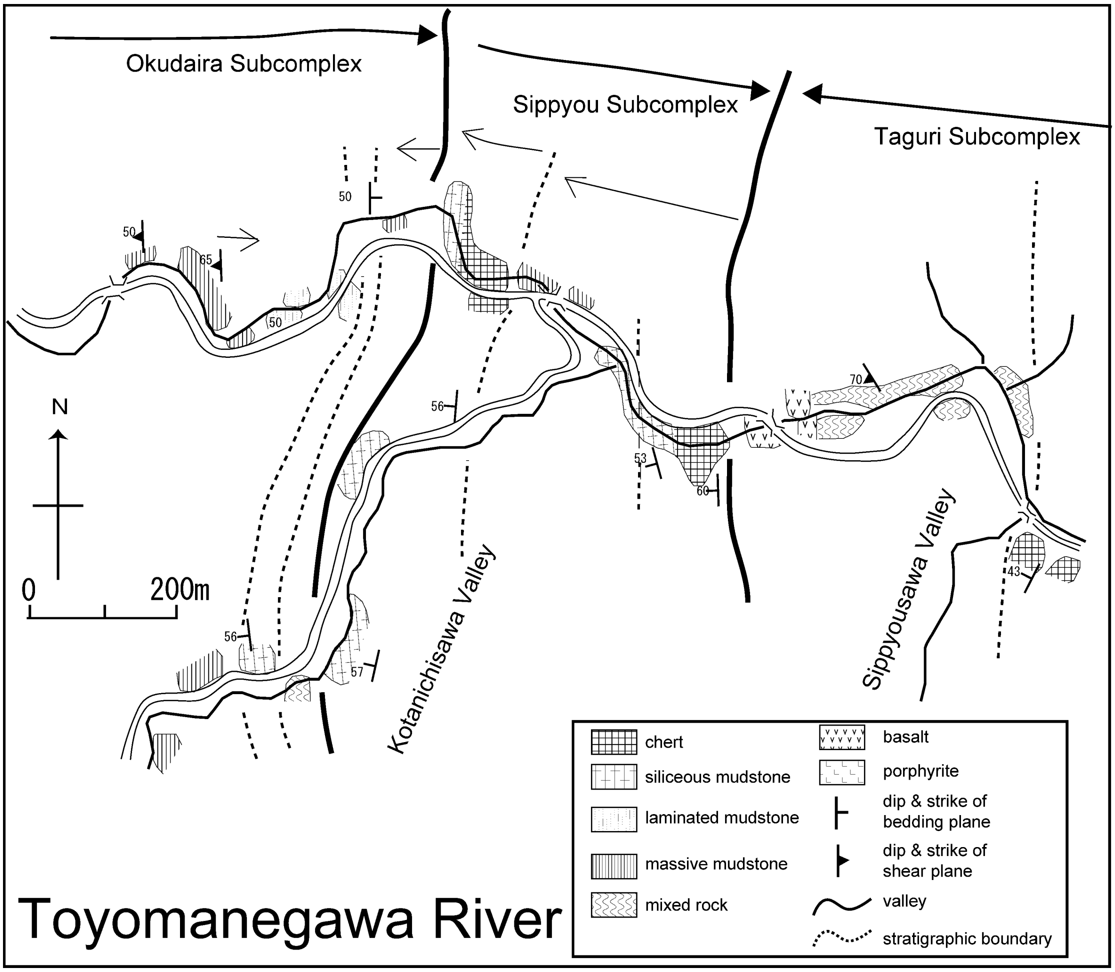


Figure 25. Field map showing the distribution of outcrops of the Taguri, Sippyou, and Okudaira Subcomplexes along the Toyomanegawa Valley. Fine arrow : a sequence of gradual changes from ribbon chert, through siliceous mudstone to mudstone in the arrow direction.

Contacts : This subcomplex is in fault contact with the Minamikawame Complex.

Fossils and age : No fossils have been found.

Comparison : The Taguri Subcomplex is easily distinguished from other subcomplexes in the Toyomane-Kazawa area by the presence of melanges.

4.4.2. Sippyou Subcomplex (new ; Sy)

Type locality : Elevations ranging from 170 to 200 m in the Sippyouzawa Valley.

Definition : A repetition of chert-clastics sequences that is overlain structurally by the Okudaira Subcomplex.

Lithology : The Sippyou Subcomplex is characterized by a pile-nappe structure of chert-clastics sequences. This chert-clastics sequence starts from brownish-gray to gray ribbon chert and is followed by dark-gray to black siliceous mudstone and gray mudstone (Figs. 26d, 26e).

Distribution : The Sippyou Subcomplex has limited distributed south of the Toyomane-Kazawa area and disappears toward the north (Figs. 6, 7).

Main outcrops : Dark-gray mudstone with thin sandstone layers is characterized by well-developed scaly cleavage near the mouth of the Kakeuchi Valley. The strike and dip of the scaly cleavage are N 11°W and 57°W. Bedded siliceous mudstone crops out immediately to the west of the black mudstone. Dark-gray ribbon chert and dark-gray bedded siliceous mudstone are repeatedly exposed in the Toyomanegawa Valley (Fig. 25). A repetition of the sequence in the I branch of the Toyomanegawa Valley (Fig. 22) starts from black mudstone with scaly cleavage, followed by gray to black mudstone interbedded with mudstone and brown and dark-gray ribbon chert. It is noteworthy that part of this sequence yields manganese nodules (Fig. 2 of Suzuki and Ogane, 2004). According to Suzuki and Ogane (2004), this sequence attains a thickness of 350 m with three fault-bounded sequences (Units 1, 2, and 3), which start as ribbon chert, followed by siliceous mudstone and then by mudstone. Each unit is characterized by an upward-coarsening sequence toward the west. Unit 1 (65 m thick) starts as ribbon chert, followed by siliceous mudstone and mudstone.

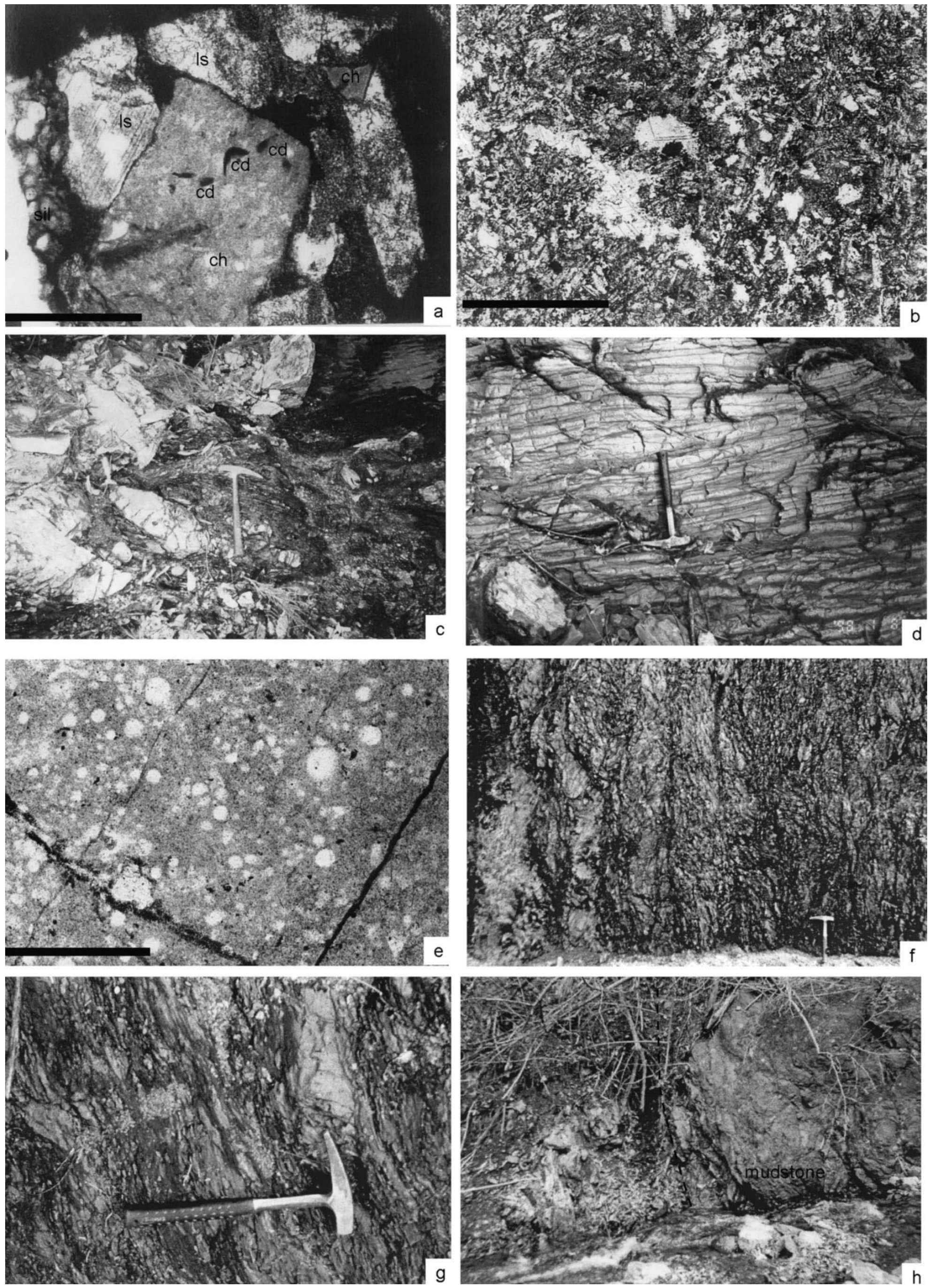


Figure 26. (a) Photomicrograph of siliceous mudstone, chert, and limestone breccia collected from the mouth of the Men'nabesawa Valley ; ch : chert, cd : conodont fossils, ls : limestone, sil : siliceous mudstone. Plane polarized light. Scale bar=1 mm. (b) Photomicrograph of volcanic rock in limestone-breccia collected from the mouth of the Men' nabesawa Valley. Plane polarized light. Scale bar=1 mm. (c) Mixed rock of the Taguri Subcomplex in the I branch of the Toyomanegawa Valley. The length of the hammer handle is 30 cm. (d) Bedded siliceous mudstone of the Sippyou Subcomplex in the Toyomanegawa Valley. The length of the hammer is 30 cm. (e) Photomicrograph of siliceous mudstone showing dissolved radiolarian tests. Scale bar=1 mm. (f) The gouge zone of the boundary between the Okudaira and Nagaiwamori Subcomplexes in the Warabinosawa Valley. The length of the hammer handle is 30 cm. (g) The boundary between the Fukushi and Okudaira Subcomplexes in the Kaneyamasawa Valley. Scale for the length of the hammer handle is 30 cm. (h) The boundary between the Okudaira (right) and Nagaiwamori (left) Subcomplexes in the Hosogoesawa Valley. The base of photograph shows approximately 3 m.

The ribbon chert gradually changes into siliceous mudstone within a 5-m-thick interval, and siliceous mudstone grades into 20-m-thick mudstone. Manganese nodules occur in mudstone within a horizon 10 cm above the boundary between mudstone and siliceous mudstone and at a horizon 360 cm above the boundary. The lower nodules are discontinuous lenses with a thickness of 3 cm. The upper nodules are ellipsoidal to spherical in shape and 20-30 cm in diameter. The west side of Unit 1 is in fault contact with Unit 2. Unit 2 consists of red ribbon chert (10 m thick), siliceous mudstone (30 m), and mudstone (10 m). The boundary between ribbon chert and siliceous mudstone is covered with talus. The siliceous mudstone changes conformably into mudstone. Nodules are found at two horizons in the mudstone. The lower manganese nodules are black elliptical nodules with diameters of 20-30 cm, while the upper nodules form an interbedded layer 20 cm thick. Radiolarians are found in the lower manganese nodules of Unit 2. Unit 3 adjoins Unit 2 on the west side of the section. Unit 3 starts as a dark-gray to gray siliceous mudstone (5 m thick) and then changes to gray to light-gray mudstone (20 m). A single manganese horizon is recognizable at a horizon 15 m above the boundary between the siliceous mudstone and mudstone. Manganese nodules are 20-30 cm in diameter and spherical to ellipsoidal in shape.

In the Toyomanegawa Valley, a sequence of thickly bedded chert, scaly cleavage-bearing black massive mudstone, gray to dark-brown ribbon chert, and siliceous mudstone crops out. The strike and dip of the bedding of the Sippyou Subcomplex are generally N 20°-50°W and 60°-75° W.

Thickness : An apparent thickness of this subcomplex is 350-700 m.

Contacts : Probable fault contact.

Fossils : Late Aalenian (Middle Jurassic) radiolarians have been found in a manganese nodule which are included in mudstone facies, not in siliceous mudstone, in the I branch of the Toyomanegawa River (Suzuki and Ogane, 2004 ; Yoshihara *et al.*, 2002).

Comparison : This subcomplex is characterized by a chert-clastics sequence with manganese nodules.

4.4.3. Okudaira Subcomplex (new ; Ok)

Type locality : Elevations ranging from 250 to 370 m in the Okudairasawa Valley.

Definition : Massive black mudstone and bedded siliceous mudstone.

Lithology : This subcomplex consists mainly of massive black mudstone which is very rarely intercalated with discontinuous thin sandstone layers. The base of the subcomplex is occasionally comprised of dark-gray to brownish-gray ribbon chert (with a total thickness less than 50 m). Millimeter-scale parallel-laminated mudstone becomes dominant upwardly in this subcomplex.

Distribution : This subcomplex patchily crops out in a NNW trend with a western dip at elevations ranging from 200 to 270 m in the Toyomane-Kazawa area and with an eastern part along the Heigawa River in the western Moichi area (Figs. 6-8).

Main outcrops : Slaty cleavage-bearing, massive black mudstone predominates in the Nagasawa Valley. The strike and dip of the cleavage are NNW and 50°-60°W. Massive black mudstone is dominant in the Shimochizawa Valley. Parallel-laminated mudstone of the eastern part of the Okudaira Subcomplex is found in the Okudaira Valley ; the bedding of the mudstone strikes N 23°W and dips 52°W. In the 250 m west from the subcomplex's base, a transition sequence from dark-brown ribbon chert (with a total thickness of 40 m) to cleavage-bearing, massive black mudstone is observable. This mudstone occasionally changes into parallel-laminated, dark-gray mudstone. Crushed chert in the western margin of the Okudaira Subcomplex is traceable throughout the Toyomane-Kazawa area.

Black mudstone of the Okudaira Subcomplex is in fault contact with alternating mudstone and sandstone of the Nagaiwamori Subcomplex in the Toyomanegawa Valley (Fig. 25). The strike and dip of the bedding of the ribbon chert (a total thickness of 5 m), 5 m upstream from this point, are N 21°W and 33°W, respectively, and this chert is sandwiched in cleavage-bearing black mudstone. The cleavage of the mudstone has a strike of N 3-8°W and a dip of 40-50°W. The Okudaira Subcomplex west of this chert is occupied by a 50-m-thick, parallel-laminated, black mudstone interbedded with fine-grained sandstone layers. Laminations in the black mudstone become indistinct westwardly, and the western margin of this subcomplex is characterized by massive black mudstone.

The Okudaira Subcomplex distributed in the Toyomanegawa Valley is massive black mudstone without cleavage. The western part of the subcomplex starts from dark-gray bedded siliceous mudstone and becomes parallel-laminated black mudstone to the west. The far western margin of the subcomplex is frequently intruded with a feldspathic porphyrite dike sheet (<100 m thick). Massive black mudstone crops out in the upper stream from a mud-control dam in the Toyomanegawa Valley. The bedding of the parallel-laminated black mudstone has a strike of N 7°E and dip of 65°E near the Kogozukatasawa Valley. This black mudstone is followed by black mudstone with chert breccias (1 mm-1 cm in diameter). The size of the chert breccia increases westwardly. A broken formation of chert and siliceous mudstone with cleavages (N 5°E, 60°W) is widely distributed in the upper Kogozukatasawa and Toyomanegawa valleys (Fig. 25).

The base of the Okudaira Subcomplex is a cleavage-bearing black mudstone in the Kotanichizawa Valley. Dark- gray bedded siliceous mudstone, associated with dark-gray mudstone beds, occupies the area 80 m west of the base. Each bed attains a thickness of 5-10 cm. The bedding of siliceous mudstone has a strike of N 23°E and dip of 57°W. This bedded siliceous mudstone gradually changes into bedded black mudstone in the west. The transition intervals from siliceous mudstone to mudstone are 50 m thick. White massive chert and siliceous mudstone are exposed 50 m upstream from the outcrop of mudstone, followed by dark-gray mudstone. West of this outcrop, cleavage-bearing black mudstone with thin sandstone layers and blocks of chert measuring 1-10 cm thick are exposed.

The cleavages of the black mudstone strike N 10°W and dip subvertically.

Massive black mudstone associated with thin sandstone layers is observable along the road to the non-operational Moichi Ore Mine in the southwestern Moichi area. The bedding of the massive mudstone strikes N 30°W and dips 60°W, and northwest-striking cleavages are well developed in the western part of the subcomplex.

Massive black mudstone with a NNW-striking cleavage crops out in a west-trending valley near the mouth of the Warabinosawa Valley. Black mudstone associated with sandstone laminae attains a maximum thickness of 200 m in the Sensoku Valley. Black mudstone with a thickness of 250 m strikes N 30°W and dips 85°W in the Hosogoezawa Valley, where northwest-striking cleavages develop in this mudstone. Phyllitic mudstone (250 m thick) with densely developed cleavages is exposed in the upper end of the Ohfunasawa Valley. Mudstone is occasionally interbedded with thin sandstone laminae and sandstone-pebble beds in the Kitakawamesawa Valley. The bedding of the mudstone in this valley strikes N 45°W and dips 60°W. Massive black mudstone crops out in the upper Kakunosawa Valley. Massive black mudstone with discontinuous sandstone layers is distributed near the end of the Kami'okutorisawa Valley.

Thickness : A thickness of 100-1500 m.

Contacts : The Okudaira Subcomplex is structurally separated from the Nagaiwamori Subcomplex by the NNW-trending, vertical Warabinosawa Fault in the east (Figs. 26f, 26g). The Okudaira Subcomplex is bounded from the Fukushi Subcomplex by a 200-m-thick shear zone (Fig. 26h).

Fossils and age : No fossils are found in the Okudaira Subcomplex.

Comparison : The Okudaira Subcomplex is easily distinguished from other subcomplexes by the dominance of massive black mudstone with or without discontinuous sand layers.

4.4.4. Fukushi Subcomplex (new ; Fk)

Type locality : Elevations ranging from 300 to 400 m in the Ko-shimochizawa Valley.

Definition : Millimeter- to centimeter-scale, parallel-laminated mudstone.

Lithology : This subcomplex is dominated by parallel-laminated mudstone with a small amount of alternating sandstone and mudstone (Figs. 27a, 27b, 27c). In the area along the Heigawa River it is also associated with the disrupted formations and melanges. The sandstone passes progressively upwards into parallel-laminated mudstone in a range of few centimeters. Sandstone is green or grayish-brown, very fine- to medium-grained feldspathic wacke, interbedded in intervals between 1-50 cm thick. The mudstone thickness ranges from 20 cm to several meters. Centimeter-scale slump beds are occasionally observed. The base of the Fukushi Subcomplex in the Toyomane-Kazawa area is characterized by a 10- to 30-m-thick, light-gray ribbon chert. This chert swells and thins but is traceable over a distance of tens of kilometers in the study area (Fig. 27d). The strike and dip of the bedding of alternating sandstone and mudstone are generally NNW-SSE and 40°-50°W.

Distribution : The Fukushi Subcomplex is patchily distributed parallel to the western boundary of the Okudaira Subcomplex in the Toyomane-Kazawa and southwestern Moichi areas (Fig. 7). This subcomplex widely crops out along the Heigawa River and downstream parts of the Oguni River (Fig. 8). The Fukushi Subcomplex predominates in the lower elevations in the northeastern area of southwestern Moichi. Isolated distribution of the subcomplex is also found in the southwestern part of Mount Nenekomori (Fig. 8).

Main outcrops : Small outcrops of sandstone and mudstone are found on ridges between the Nagasawagawa and Ohkawa valleys, between the Ohtanichi and Kotanichi valleys, and between the Kotanichi and Sippyouzawa valleys (Figs. 7, 11). The following lithologies are distributed on the ridge west of the Ko-shimochizawa Valley : limited exposures of mudstone at 300 m elevations, sandstone-dominant alternating sandstone and mudstone at 340 m elevation, mudstone interbedded with thin sandstone beds (<1 cm thick) at 350 m elevation, pebbly conglomerate with mudstone at elevations ranging from 350 to 430 m, and a 50-cm-thick sandstone containing chert pebbles at 430 m elevation. This conglomerate grades into mudstone over a 1.5-m interval. A typical parallel-laminated mudstone of the Fukushi Subcomplex is exposed in the Kaneyamazawa and Miyako-Funezawa valleys. This mudstone gradually changes into alternating sandstone and mudstone in the Kaneyamazawa Valley. The parallel-laminated mudstone is distributed along the road for the non-operational Moichi Ore Mine and has well-developed cleavage. On the other hand, cleavage is indistinct in mudstone in the Sensokusawa and Kitakawamesawa valleys. Dark-gray, parallel-laminated mudstone crops out along the Heigawa River between Horoiwa and Kawai-o'hashi Bridge. This mudstone partly shows boudin and slump structures. The original structure of the contorted silt-laminated turbiditic mudstone unit is relatively preserved ; slump folds have wave lengths of a few meters. Local intraformational breccia is occasionally developed in the slumps. Slip planes are well developed.

Millimeter-scale, parallel-laminated, massive black mudstone is exposed along the road in the Shimonosawa Valley, in the A branch of the Kawai-minamizawa Valley. The cordierite-bearing, parallel-laminated mudstone strikes N 25° W and dips 82°SW in the C branch of the Kawai-minamizawa Valley. Brownish-gray mudstone crops out near small plutonic rocks (< 100 m diameter) in Shimokawai. Cleavage-bearing black mudstone with sandy mudstone lenses and massive black mudstone with sandy lamination crop out in the lower A branch of the Naka-no-matazawa Valley. Ribbon chert (10 m thick) and cleavage-bearing black mudstone with medium-grained sandstone lenses are widely distributed in the C and D branches of the Nakanomatazawa Valley.

Mudstone with thin-grading sandstone layers strikes in a northwest trend in a south branch of the Hon'munesawa Valley. The sandstone layers thicken upwardly, and the upper part of this subcomplex shows gradual changes into alternating sandstone and mudstone. This mudstone is

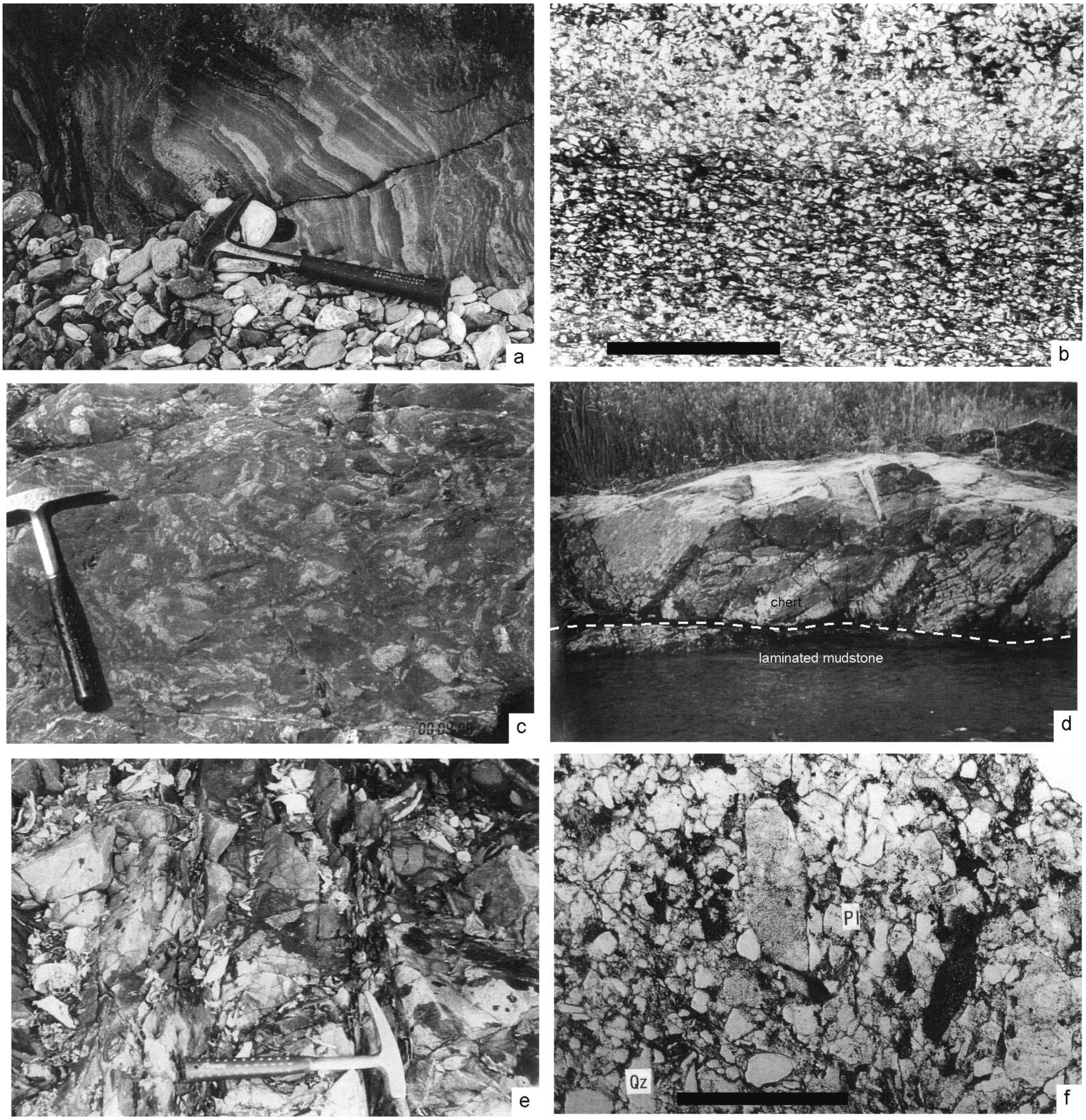


Figure 27. (a) Upward-fining laminated mudstone of the Fukushi Subcomplex, Horoiwa. The hammer handle length is 30 cm. (b) Microphotograph of laminated mudstone of the Fukushi Subcomplex collected from the Miyakofunesawa Valley. Plane polarized light. Scale bar = 2.5 mm. (c) Broken formation of the laminated mudstone of the Fukushi Subcomplex in the lower Sen'notairasawa Valley. (d) The boundary fault between the laminated mudstone and the overlying chert. Fukushi Subcomplex along the Hei'gawa River. (e) The sandstone-dominant, alternating sandstone and mudstone of the Furuyadomori Subcomplex cropped out along the road to the non-operational Moichi Mine. (f) Photomicrograph of the sandstone of the Furuyadomori Subcomplex, collected from the Yumenokihirasawa Valley. Qz : quartz, Pl : plagioclase.

weakly folded in an E-W trend in this valley. Black mudstone with sandstone layers is distributed in the upper Kakakunosawa Valley. Thermally metamorphosed mudstone with sandstone layers crops out near the plutonic rocks of Mount Maekariyama in the upper Kakunosawa Valley. Black mudstone with thinly grading sandstone layers crops out in the Kami'okutorisawa Valley, in Uenodai, and in the Nakiuchisawa Valley. Outcrops of sandstone and mudstone are found in the west branch of the Nashigahorasawa Valley where the mudstone is intercalated with gray, medium- to coarse-grained, grading sandstone layers.

Black mudstone intercalated with sandstone layers is also found around the Tanosawa Valley. Sandstone layers thicken stratigraphically upward from several millimeters at the mouth of the valley to 5-15 cm thick in the upper end of the valley. Mudstone with millimeter-scale sandstone laminations crops out in the lower Shimonosawa Valley. In the middle to upper Shimonosawa Valley, the sandstone bed generally attains a maximum thickness of 3-5 cm. Mudstone with millimeter-scale sandstone laminations also dominate in the lower Yukihirasawa Valley. Massive sandstone is also found at 360 m elevation. At 400 m in elevation, a 100-m thick crush zone is developed between the massive sandstone and black mudstone with millimeter-scale sandstone laminations. Massive gray sandstone crops out at elevations ranging from 420 to 460 m. A NW-striking, east-dipping mudstone with grading sandstone layers is exposed at elevations higher than 460 m.

Parallel-laminated mudstone and fining-upward grading mudstone are exposed at the mouth of the Sakamotosawa Valley. Intrafolially folded, gray ribbon chert associated with black mudstone widely crops out along the lower 1000-m intervals from the mouth of the Sakamotosawa Valley. Ribbon chert is also distributed on the west slope of the valley. Black mudstone is widely distributed in the middle to upper Sakamotosawa Valley. This mudstone intercalates 1-m thick tuff and grades from sandstone in this valley.

Gray ribbon chert associated with massive black mudstone is exposed along 400-m intervals from the point where the I branch of the Sakamotosawa Valley joins the Sakamotosawa Valley and in the lower II branch of the Sakamotosawa Valley. Weakly parallel-laminated black mudstone crops out in the middle to upper I branch of the Sakamotosawa Valley. This mudstone is folded with a half-wavelength of 100 m. Black mudstone with a few sandstone layers crops out in the middle II branch of the Sakamotosawa Valley and is followed by weakly parallel-laminated mudstone in upper part of this valley.

The Fukushi Subcomplex in the Ohsawa Valley, Moichi, and Mitsuishi is marked by disrupted, broken formations with occasional blocks of chert and sandstone. A typical disrupted subcomplex with exotic chert blocks is observable along the Heigawa River between Mitsuishi and Suijin. Sandstone layers are also disrupted in this facies. The long axes of these chert blocks generally range from 10 to 40 cm in length, but in extraordinary cases can reach several meters. These blocks are usually oriented parallel to a northwest-trending subvertical shear plane showing left-lateral movements. The Fukushi Subcomplex in this place is weakly thermally metamorphosed. Disrupted formations without chert blocks are typically distributed in the Sen'notairasawa Valley. Broken formations of sandstone and millimeter-scale parallel-laminated mudstone are widely distributed in the lower Sen'notairasawa Valley. These blocks, which are several to tens of meters in size, have angular outlines. Some sandstone blocks are apparently separated from the mudstone matrix by a sharp contact. This sandstone is wacke comprised of angular quartz and feldspathic grains (0.1-0.2 mm in diameter) with a very fine-grained sandy matrix.

Melange facies with angular to rounded chert blocks (5-10 cm thick) and a small amount of sandstone blocks widely crop out in the middle to upper Sen'notairasawa Valley. Microscopy reveals a matrix of mica minerals. A broken formation with layered blocks of sandstone, angular sandstone, and a few cherts is distributed in and around the Kaneyamazawa Valley. Weakly broken formations are observable along the Ohsawa Valley where alternating boudin sandstone and parallel-laminated mudstone are exposed. The sandstone changes progressively upwards into mudstone. Angular sandstone blocks with parallel-laminated sandy mudstone are also distributed in the Fujibiransawa Valley. Relatively rounded sandstone clasts and massive mudstone are weakly disrupted in the Uchinosawa Valley. The original structure of sandstone and mudstone is preserved in the outcrops in the upper Uchinosawa Valley. Small blocks of ribbon chert are patchily found in the Fukushi Subcomplex in the Toyomane-Kazawa area. In contrast, chert is widely distributed in Mitsuishi. This chert has variegated colors of gray, yellowish-brown, brown, and red, strikes to the east-northwest, and dips subvertically. The chert attains a maximum thickness of 100 m and structurally overlies clastic rocks of the Fukushi Subcomplex along the Heigawa River. The boundary is a fault with an absence of gauge zones, which strikes N 20°W and dips 40° W. Lineations on this fault are oriented N 70°W.

Massive black chert is widely distributed in the lower 1200-m intervals of the Ohsawa Valley. Small outcrops of massive mudstone, broken formations, and white ribbon chert are also found in this valley. Ribbon chert transitionally changes into black mudstone with sandstone lenses in the lower Urushizawa Valley. The siliceous mudstone between ribbon chert and mudstone attains a thickness of 60 cm. Ribbon chert and black mudstone crop out along the road to the non-operational Haigura Ore Mine. Large outcrops of ribbon chert and black mudstone are found in south-trending valleys from Suijin.

The strike and dip of the Fukushi Subcomplex bedding are generally NNW-NW and 30°-70°W in the eastern part of southwestern Moichi, in the southeastern part of northwestern Moichi, and along the Heigawa River between Kawai and Haratai. This subcomplex partly strikes NW-EW and dips to the south in Horoiwa, in the Shimonosawa Valley, in the C branch of the Kawai-minamizawa Valley, and in the upper Nakiuchisawa Valley. In the Kami'okurisawa Valley, the bedding of this subcomplex strikes NNW and dips 70°-80°E. In the Tanosawa Valley, bedding strikes E-W and dips 30°-50°S in the lower to upper parts of the valley and NE and NW at the upper end of the valley. Strike and dip patterns are highly variable in the middle to upper Shimonosawa Valley.

Thickness : This subcomplex thickens northwestwardly, measuring 100 m in the Nagasawa Valley to 200 m at the type locality in the Toyomane-Kazawa area. The thickness ranges from 250 to 900 m in the southeastern Moichi area.

Contacts : The base of the Fukushi Subcomplex is separated by NNW-SSE striking and steeply west-dipping faults in the Toyomane-Kazawa and southeast Moichi areas. Locally, the boundary dips very shallowly to the east in the Shimochizawa Valley in the Toyomane-Kazawa area.

Fossils and age : No fossils are found in the Fukushi Subcomplex.

Comparison : In contrast to overlying clastic rocks such as the Furuyadomori Subcomplex, the Fukushi Subcomplex is dominated by laminated mudstone.

4.4.5. Furuyadomori Subcomplex (new ; Fy)

Type locality : In the Ohkawa Valley.

Definition : The Furuyadomori Subcomplex is defined by sandstone-dominant alternating sandstone and mudstone (Figs. 27e, 27f). This subcomplex is locally associated with several sets of ribbon chert attaining thicknesses of several tens of meters.

Distributions : The Furuyadomori Subcomplex is mainly distributed in the southwestern Moichi and Kawai areas, whereas it is patchily distributed in Toyomane-Kazawa and in the southeastern part of southwestern Moichi.

Lithology : The sandstone is very fine- to medium-grained feldspathic wacke with a minor amount of lithic arenite. This sandstone generally grades into mudstone, and the sandstone beds generally range in thickness from several to tens of meters. Ribbon chert in the Furuyadomori Subcomplex attains an apparent thickness of 20-50 m. A ribbon chert a few meters thick is discontinuously traced in the Toyomane-Kazawa and southwest Moichi areas. Four horizons of ribbon chert named Fr+1, Fr+2, Fr+3, and Fr+4 are recognized in the Kawai area (Fig. 8). Conglomeratic sandstone is occasionally intercalated in the sandstone. This conglomerate is generally sandy, matrix-supported, monomictic conglomerate, consisting of irregularly shaped cherts up to several centimeters in diameter. The sedimentary structure appears massive, but the thicknesses and shape of the conglomeratic sandstone are unknown.

Main outcrops : The Fr+1 chert is found as a basal part of the Furuyadomori Subcomplex, which is followed by sandstone-dominant alternating sandstone and mudstone along the Nagasawa River. Fine- to medium-grained, massive, grayish-brown sandstone of the Furuyadomori Subcomplex is in fault contact with the Okudaira Subcomplex in the Ohkawa Valley. Sandstone with lithic grains of chert, siliceous mudstone, and shale, and associated chert breccia of the Fr+1 chert horizon are well exposed at 600 m elevation in the Kaketatsuzawa Valley. Alternating thick sandstone (50 cm to several meters thick) and thin mudstone (<20 cm thick) crops out in the Kogawa Valley. The lower part of the subcomplex is tectonically crushed in this valley. Sandstone-dominant alternating sandstone and mudstone are widely distributed in the Shimo-Kobayorizawa Valley, followed by the thermally metamorphosed, white to gray ribbon chert of the Fr+2 chert. Another Fr+2 chert outcrop is also found in the Okudaira Valley, which is associated with an 80-m-thick, massive, black mudstone.

A porphyrite dike intrudes into the boundary between the Furuyadomori and Okudaira Subcomplexes in the lower Tsugaruishi Valley. The westward transition from gray or grayish-brown ribbon chert to siliceous mudstone lies adjacent to this dike sheet in this valley. The massive white chert of the FR+2 chert crops out immediately west of this siliceous mudstone.

Alternating sandstone and mudstone typical of the Furuyadomori Subcomplex is observed along the road to the non-operational Moichi Ore Mine and in the Kohaigurasawa Valley. Well-sorted, coarse-grained, dark-gray sandstone is found in the upper Kaneyamazawa Valley. Mudstone (250 m thick) and ribbon chert (100 m thick) of the FR+2 chert are widely distributed in the Kitakawamesawa Valley. This mudstone changes progressively upwards into massive sandstone in this valley. Poorly sorted, coarse-grained, massive, black sandstone attains an apparent thickness of 500 m in upper parts of the Kitakawamesawa and Karowazawa valleys. A 50-m-thick ribbon chert of the FR+3 chert crops out on the slope of the Koshika'uchisawa Valley and is overlain structurally by massive, well-sorted, white sandstone with a small amount of rip-up clasts. The Furuyadomori Subcomplex along the road to the Haigura Mine is subdivided into sandstone-dominant alternating sandstone and mudstone, a 10-m-thick ribbon chert of the FR+3 chert, and massive, well-sorted, medium-grained, dark-gray sandstone. The poorly sorted, medium- to coarse-grained, dark- gray sandstone is exposed in the Urushizawa Valley.

The FR+2 chert and overlying alternating sandstone and black mudstone are well exposed from the middle to upper Sen'notairasawa Valley. This sandstone is well sorted, fine to medium grained, and massive. Similar ribbon chert and clastic rocks to those in the Sen'notairasawa Valley crop out in small valleys of the upper Ohsawa Valley. The ribbon chert ranges in thickness from 100 to 300 m, whereas the clastic rocks are comprised of sandstone, mudstone, and sandstone-dominant alternating sandstone and mudstone. A 50-m-thick ribbon chert of the FR+2 chert and a 500-m-thick, well-sorted, medium-grained, dark-gray, massive sandstone are exposed in a valley on the eastern slope of the upper Ohsawa Valley. The sandstone has been thermally metamorphosed into hornfels near the Cretaceous Nenekomori Pluton in the Waka'anasawa and Uchinosawa valleys. In the south of Haratai, black mudstone is underlain by ribbon chert of the Kotanichi Subcomplex.

Alternating, fine-grained sandstone and mudstone are exposed at elevations above 400 m in the West Nashigahorasawa Valley. The thickness of each bed varies from several centimeters to 4 m. The Furuyadomori Subcomplex gradually changes from mudstone-dominant clastic rocks in the lower part of the valley, to parallel-laminated mudstone at 600 m elevation, to very fine- to fine-grained sandstone at elevations above 600 m. Small outcrops of sandstone occur at elevations ranging from 350 to 500 m on the ridge west of the Tanosawa Valley. Mudstone floats are also found in the same places, suggesting that the alternating sandstone and mudstone are distributed in this area. Fine- to medium-grained, gray to light-gray sandstone crops out in the middle Yumenokihirasawa Valley.

Cherts of FR+1, FR+2, and FR+3 are typically developed in the Kawai area. Sandstone-dominant alternating sandstone and mudstone below the FR+1 chert can be observed near the operational Kawai Quarry. Thermally metamorphosed, biotite-bearing sandstone and mudstone beneath the FR+1 chert are exposed in the middle to upper Itamotosawa Valley where the bedded sandstone thickens stratigraphically upwards. The basal part of the Furuyadomori Subcomplex at the upper end of a valley north of Shimokawai is dominated by conglomeratic sandstone and sandstone below the FR+1 chert. This conglomeratic sandstone is matrix-supported, poorly sorted, and yields angular granules of abundant chert and minor mudstone. Alternating sandstone and mudstone interbedded with conglomeratic sandstone beneath the FR+1 chert are also exposed in the middle of A valley in Kawai. The sandstone is well sorted and gray to dark-gray in color, whereas the conglomeratic sandstone is matrix supported, well sorted, and contains angular granules of chert and mudstone. Biotite-cordierite-quartz-feldspar hornfels beneath the FR+1 chert crop out well at elevations higher than 400 m in the C valley in Kawai. A northwest-striking, vertical-dipping, parallel-laminated, black mudstone beneath the FR+1 chert is characterized by well-developed slaty cleavage along the road at elevations higher than 350 m in Katasu.

The Fr+1 chert in the upper Kawai Valley starts as ribbon chert, followed by siliceous mudstone, and then broken formations of alternating sandstone and mudstone. A similar transition sequence of the FR+1 chert is also found at elevations ranging from 370 to 430 m in the Su'nai D valley. Another transition sequence of the FR+1 chert, from ribbon chert (each bed 2-3 m thick) to less-laminated siliceous mudstone, crops out 2 km east of the mouth of the Katasu Valley. A transition sequence from siliceous mudstone to massive sandstone with rip-up clasts above the FR+1 chert is found along the road in Katasu where the siliceous mudstone yields non-fossiliferous manganese nodules (approximately 10 cm in diameter). Massive chert of the FR+1 chert crops out at elevations below 350 m in a valley west of Fukado. Alternating chert and mudstone that correlate to the uppermost part of the FR+1 chert are observed at elevations lower than 800 m on the southern slope of the Nakanomatazawa D valley.

The FR+2 chert starts as ribbon chert, followed by siliceous mudstone, and then broken formations of alternating sandstone and mudstone in the area 1 km east of the mouth of the Kaizawa Valley. Siliceous mudstone above the FR+2 chert yields radiolarian-bearing manganese nodules (5-15 cm in diameter). Clastic rocks above the FR+2 chert are characterized by sandstone and cleavage-bearing mudstone in the middle Kaizawa Valley. Ribbon chert of the FR+3 chert crops out at elevations lower than 400 m in the A branch of the Kaizawa Valley. Sandstone interbedded with mudstones (10 cm thick) structurally overlies ribbon chert of the FR+3 chert in this valley. Massive sandstone and mudstone-dominant alternating, weakly laminated sandstone and mudstone are located above the FR+3 chert in the middle to upper Kaizawa Valley.

In the Kaizawa, Kitakawamesawa, and Kohaigurasawa valleys, and south of Haratai, the strike and dip of the Furuyadomori Subcomplex generally range from N 30°W-60° W and 20°-45°W. Along the road to the non-operational Haigura Mine, sandstone dominates, and the strike and dip are N 50°W and 25°W.

An east-trending strike ranging from N 20°E to N 50°E for sandstone and mudstone is found in the upper Tsugaruishi Valley and along the road to the non-operational Haigura Mine ; the dip is generally shallower than 50°W in these areas. The strike and dip of the bedding of the sandstone are occasionally N 20°E and 45°E in the Urushizawa Valley and N 55°W and 35°E in the upper Kaneyamazawa Valley, respectively, and N 20°-40°W and 20°-50°NE near the operational Kawai Quarry. The ribbon chert generally has variable strikes and dips.

Thickness : The Furuyadomori Subcomplex is 1000 m thick in the southwestern Moichi area, followed by a progressive decrease in thickness toward Toyomane-Kazawa (ca. 50-250 m thick), southeastern Moichi (100-200 m thick), and northwestern Moichi (< 100 m thick).

Contacts : The boundaries of the Furuyadomori Subcomplex are in fault contact with the underlying Fukushi and overlying Kotanichi Subcomplexes. Cataclasite has developed between the Furuyadomori and Kotanichi Subcomplexes.

Comparison : The Furuyadomori Subcomplex is easily distinguished from other subcomplexes by the presence of alternating sandstone and mudstone, and from the Kariya Subcomplex by the lack of well-rounded boulders in the conglomerate.

Fossils and age : The Fr+1 chert horizon exposed along the Oguni River contains Late Triassic conodonts, including *Grodella delicatula* (Mosher), *Misikella hernsteini* (Mosher), and *Neohindeolella suevica* (Tatge) (Yoshida, 1980). The Fr+1 chert horizn in the Ohkawa Valley also contains the Uppter Triassic conodonts (Murai *et al.*, 1983). The Fr+3 chert horizon in the Toyomane-Kazawa area contains the Pb element of *Cornudina breviramulis* (Tatge). Although this species had a wide biostratigraphic range between the early Olenekian (Early Triassic) and Norian (Middle Triassic), the number of denticles tends to be reduced in fossils of younger age. The smaller number of denticles in the obtained specimen suggests that it dates to the Anisian (Yamakita, personal communication).

Siliceous mudstone of the Furuyadomori Subcomplex in the Kaizawa Valley yields radiolarian-bearing manganese nodules. One nodule contained 25 radiolarian species, including *Eucyrtidiellum disparile* Nagai et Mizutani, *E. unumaense* (Yao), *Foremanina veghale* Kozur, *Parahsuum* cf. *parvum* Takemura, *Trillus* sp. C of Yao (1997), *Unuma* cf. *echinatus* Ichikawa et Yao, and *U. typicus* Ichikawa et Yao. The joint occurrence of *U. typicus, U.* cf. *echinatus*, and *Trillus* species is assigned to the JR3 Zone of Matsuoka (1995), which dates to the Aalenian (Fig. 28).

4.5. Karomori Complex (new)

4.5.1. Kotanichi Subcomplex (new ; Kt)

Type locality : Along the Ohtanichizawa Valley, a branch of the Toyomanegawa Valley (See figures in Okami, 1990 and Okami *et al.*, 1993).

Definition : Ribbon chert associated with limestone and mafic volcaniclastic rocks and with manganese ore deposits.

Lithology : The subcomplex consists of white to gray

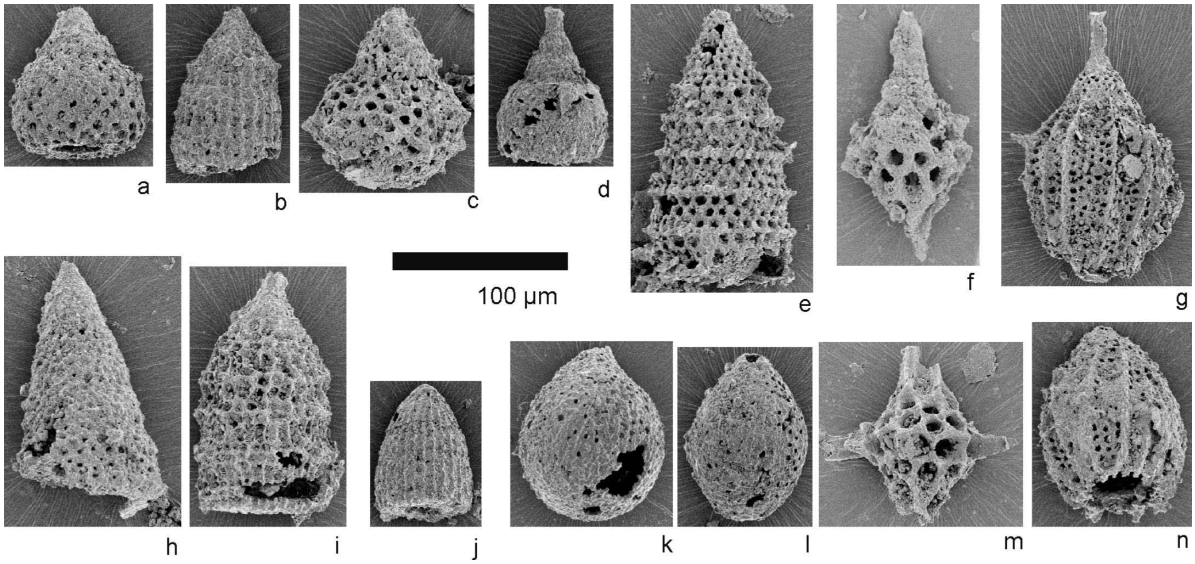


Figure 28. Selected Aalenian radiolarians recovered from a manganese nodule of the Kotanichi Subcomplex in the Kaizawa Valley. (a) *Eucyrtidiellum disparile* Nagai et Mizutani, (b) *Archaeodictyomitra* cf. *gifuensis* Takemura, (c) *Arcanicapsa* sp. H2 of Yao (1997), (d) *Eucyrtidiellum unumaense* (Yao), (e) *Foremanina veghae* Kozur, (f) *Trillus* sp. C of Yao (1997), (g) *Unuma* cf. *echinatus* Ichikawa et Yao, (h) *Pseudodictyomitrella* (?) sp., (i) *Parahsuum* sp. T018 of Suzuki and Ogane (2004), (j) *Parahsuum* sp. C of Yao (1997), (k) *Tricolocapsa* sp., (l) *Tricolocapsa* cf. *tegiminis* Yao, (m) *Zartus* sp. cf. *Zartus* sp. B of Yao (1997), (n) *Unuma typicus* Ichikawa et Yao.

ribbon chert associated with limestone, mafic volcanic rocks, clastic rocks, and siliceous mudstone. The lower part of the Kotanichi Subcomplex is occasionally associated with manganese ore and iron matter. This ribbon chert lacks interbedded muddy films and is generally overlain by massive black mudstone or pale green bedded mudstone. The limestone is massive, bluish gray, highly recrystallized, and occasionally associated with minor amounts of mafic volcanic clasts. Limestones are composed of limestone breccia in association with basaltic pebbles. The limestone is in fault contact with the underlying and overlying ribbon chert (Okami, 1990 ; Okami *et al.*, 1993). The uppermost part of the Kotanichi Subcomplex is partly associated with mudstone and siliceous mudstone.

Distribution : The Kotanichi Subcomplex is easily traceable throughout the study area as a key horizon. This subcomplex crops out at elevations ranging from 500 to 700 m on the eastern slope of Mount Yam'bo-mori, from 480 to 660 m in the Shimochizawa Valley, and from 410 to 720 m in the Kawai area. Limestone is abundantly distributed in the southeastern Toyomane-Kazawa area. This subcomplex near the Warabinosawa Fault is shallow-dipping (10-20°W) with a north strike.

Main outcrops : Recrystallized, massive, white to gray limestone (2-3 m thick) is found beneath massive, white to gray ribbon chert in the Nagasawagawa Valley. A 5-m-thick limestone and small outcrops of chert are occasionally found at elevations ranging from 500 to 660 m in the Motojukusawa Valley. Ribbon chert associated with siliceous mudstone and mudstone crops out at elevations ranging from 470 to 515 m, whereas a small outcrop of gray massive limestone is present at an elevation of 515 m in the Shimo-Kobayorizawa Valley. Limestone, white to light-gray ribbon chert with siliceous mudstone, and mudstone are exposed at elevations above 390 m in the Koyadozawa Valley. Recrystallized, massive, white to gray limestone with an absence of volcaniclastic rocks, is in fault contact with interfoliate, folded ribbon chert. This fault strikes to the E-W and dips vertically in the Minaminomatazawa Valley. A sequence of white to gray ribbon chert, bluish-gray massive limestone (50 m thick), massive chert (1 m thick), white to gray massive limestone (>3 m thick), massive black mudstone, light-green bedded mudstone (30 m thick), and white to gray ribbon chert (40 m thick), is observed at elevations higher than 400 m on the ridge between the Kitanomatazawa and Minaminomatazawa valleys. The lower limestone in this sequence is marked by a considerable amount of volcaniclastic clasts, whereas the upper limestone is marked by few volcanic clasts. The strike and dip of the boundary between the lower limestone and massive chert are N 80°W and 20°S between the Kitanomatazawa and Minaminomatazawa valleys. Recrystallized, massive, white to bluish-gray limestone (50 m thick) interbedded with basaltic volcaniclastic rocks is exposed at the joint point of Kitanosawa Valley and Minaminosawa Valley. Next to this limestone, white ribbon chert and black mudstone crop out. The west margin of the Kotanichi Subcomplex is a transition sequence from dark-gray ribbon chert to cleavage-bearing siliceous mudstone.

The basal Kotanichi Subcomplex in the Shimochizawa Valley is white to gray ribbon chert interbedded with 10-m-thick limestone. This ribbon chert is partly folded and gradually changes upward into siliceous mudstone. The sequence in the Kogawa Valley starts as bluish-gray, massive, fusulinid-bearing limestone, followed by strongly interfoliate folded and white to dark-gray ribbon chert, and then siliceous mudstone. A similar sequence of limestone, ribbon chert, and mudstone is also found in the Iwadasaniawa Valley, where the limestone is light-gray, massive, highly recrystallized, and intercalates black manganese ore deposits. The ribbon chert is white and folded and separated from the adjacent mudstone by faults with a 1-m-thick gouge zone. The upper part of the Kotanichi Subcomplex in the Nekozawa Valley is characterized by broken formations of alternating sandstone and mudstone, massive mudstone, bedded mudstone, and bedded siliceous mudstone. This unit is repeated twice in this valley. White ribbon chert, black mudstone, sandstone, and limestone are widely distributed in Otsuchi. This limestone is associated with basic volcaniclastic rocks. The upper and lower boundaries of the limestone are faulted.

Light-gray ribbon chert and hornfels of black mudstone are observable along the road to the non-operational Haigura Mine. White ribbon chert crops out around the Triangulation Station Point ("Sankakuten" in Japanese) at an elevation of 691 m, south of Haratai. Recrystallized, crinoid-bearing, massive limestone is found along the hillside up to the ridge. The lower part of the mudstone is characterized by the presence of highly altered basaltic clasts. Light-gray ribbon chert is 200 m thick in the Kitakawamesawa Valley but decreases to 100 m thick in the Sen'notairasawa Valley. Highly recrystallized chert is exposed along the roadside at the end of Ohsawa Valley and at an elevation of 450 m in the Kitsubushisawa Valley.

Gray and red ribbon chert with recrystallized black limestone and green volcaniclastic rocks is widely distributed in the Sakamotosawa-1 Valley. A similar lithology is also found in the Sakamotosawa-2 and Yumenukihirasawa valleys. Gray ribbon chert crops out at elevations ranging from 300 to 450 m in the Sakamotosawa-2 Valley. Limestone boulders are scattered in this valley. Many outcrops of recrystallized black limestone are found on the slope at elevations higher than 650 m in the Yumenokihirasawa Valley.

Mudstone and ribbon chert also crop out in Saike north of the Heigawa River. Small outcrops of gray ribbon chert, black mudstone, and mudstone with chert breccias are found in a watershed between the Maekari Valley and the Heigawa River. The strike and dip of the plane of the slaty cleavage are N 50°W and 60°E. Gray, brown, and purple ribbon chert is widely distributed at elevations ranging from 430 to 870 m in the Fukaisawa Valley. Gray and red kinked ribbon chert with mudstone continuously crops out in elevations higher than 500 m at the end of the Sakamotosawa Valley.

Recrystallized, muddy, crinoid-bearing limestone that overlies ribbon chert, and siliceous mudstone, are found in the Kaizawa Valley. The Kotanichi Subcomplex in the Kawai area occasionally yields limestone. Ribbon chert and mudstone are distributed at elevations below 400 m in the Kaizawa B valley. The same chert is exposed at 470 m in elevation in a small valley east of the Kaizawa B valley. Another ribbon chert is exposed at 400 m in a northern valley of the Kai-kaminosawa Valley and at elevations ranging from 600 to 650 m at the upper end of the Su'naizawa Valley. Massive dark-grey chert and interbedded mudstone crop out at the upper end of the Su'naizawa B valley, and this chert is intruded by iron-rich black veins.

The beddings of ribbon chert and mudstone have variable strike and dip : NW°WNW and 25-58°W in the Nagasawagawa Valley, N 65°E and 20°W along the road to the non-operational Haigura Mine, E-W and 30°-70°E in the Sakamotosawa-2 Valley, N 60°W and 30°W-40°E in the Kitakawamesawa Valley, N 25°W and 55°E in the Sen'notairasawa Valley, N 5°-10°W and 65°-70°E in the Kaizawa B valley, and N 36°-46°W and 60°N to subvertical in the Su'naizawa Valley and in a northern valley of the Kai-kaminosawa Valley.

Thickness : The apparent thickness of the subcomplex ranges from 50 to 220 m in the Toyomane-Kazawa area, from 200 to 450 m in the southwestern Moichi area, and from 150 to 250 m in northwestern Moichi, respectively.

Contacts : The Kotanichi Subcomplex is in fault contact with the Furuyadomori and Fukushi Subcomplexes of the Tsugaruishi Complex. Chert of the Kotanichi Subcomplex is in fault contact with the sandstone of the Furuyadomori Subcomplex in the Kitakawamesawa Valley. The gouge of this fault attains a thickness of several tens of centimeters and is marked by proto-cataclasite of sandstone and chert origin. Chert of the Kotanichi Subcomplex along the road to the non-operational Haigura Mine is in fault contact with mudstone of the Furuyadomori Subcomplex. This fault is also associated with proto-cataclasite of sandstone and chert origin. A gouge zone that is 3-m thick is found between the Kotanichi and Fukushi Subcomplexes at the meeting point of the Fukaisawa and Nawauchisawa valleys.

Comparison : The Kotanichi Subcomplex is easily distinguished from other subcomplexes by the presence of rich lenses of limestone and volcaniclastic rocks.

Fossils and age : Limestone blocks in Anaji, the Toyomane Valley, the Kogawa Valley, and the Ohkawa Valley yield Early Permian fusulinids, including *Chalaroschwagerina vulgaris* (Schwellwien), *Parafusulina* sp., *Pseudofusulina* sp., and *Pseudoschwagerina* sp. (Onuki, 1956, 1969 ; Sugimoto, 1972 ; Yoshida and Katada, 1964). Chert beds in the Anaji and Kitanomata ore quarries contain Late Permian to Norian (Middle Triassic) conodonts, including *Anchignathodus minutus* (Ellison), *A. typicalis* Sweet, *Epigondolella abneptis* (Huckreide), *E. mungoensis* (Diebel), *Gladigondolella tethydis* (Huckreide), *Neogondolella bisseli* (Clark et Behnken), *N. bulgarica, N. carinata* (Clark), *N. constricta* (Mosher et Clark), *N. excelsa, N. navicula hallstattensis* Mosher, *N. mombergensis* (Tatge), *N. polygnathiformis* (Budurov et Stefanov), *N. subcarinata, Neosphatodus dieneri* Sweet, *N. homeri* (Bender), and *N. newpassensis* Mosher (Okami, 1990 ; Okami *et al.*, 1993).

4.5.2. Choukomori Subcomplex (new ; Ck)

Type locality : At elevations ranging from 350 to 680 m in the Arakawa-Kogawa Valley.

Definition : The Choukomori Subcomplex is defined by sandstone-dominant clastic rocks (Figs. 29a, 29b).

Distribution : The Choukomori Subcomplex has limited distribution at elevations above 350 m in the Toyomane-Kazawa area. This subcomplex generally has a N 30°W strike trend and dips southwest in the Kitanomatazawa, Minaminomatazawa, and Kogawa valleys. In the west of the Toyomane-Kazawa area, the subcomplex changes to an E-W strike and a shallow south dip. The Choukomori Subcomplex is also distributed on topographic highs in the Nagasawa, Kitakawamesawa, and Karowazawa valleys, and a branch of the Sen'notairasawa Valley. This subcomplex is patchily found on several summits in the northwest Moichi area as well.

Lithology : The lithology of the Choukomori Subcomplex is regionally different in the study area. It is dark-gray to black mudstone with slaty cleavage in the southern Toyomane-Kazawa area, sandstone-dominant alternating sandstone and dark-gray mudstone in the north Toyomane-Kazawa area, and sandstone with a minor amount of mudstone in the southwest Moichi area. In the northern Toyomane-Kazawa area, the sandstone is well-bedded (10 cm-1 m thick), very fine- to coarse-grained feldspathic wacke with rip-up clasts. This sandstone is characterized by approximately equal amounts of potassium feldspar (K-feldspar) and plagioclase grains. Mudstone is graded from sandstone and attains a thickness of several centimeters to 10 cm. Feldspathic wacke and lithic wacke are widely distributed in the northwestern Kawai area.

Main outcrops : Sandstone predominates at elevations ranging from 430 to 490 m in the Tsubonezawa Valley. With a prominent, cleavage-bearing, dark-gray mudstone at its base, the overlying sequence of sandstone-dominant alternating sandstone and mudstone is exposed in the Kitanomatazawa Valley. The boundary of the Choukomori and Kotanichi Subcomplexes is locally intruded by a porphyrite dike sheet in this valley. Dark-gray, millimeter-scale, parallel-laminated mudstone is dominant in the lower part of the Choukomori Subcomplex in the Shimochizawa Valley. The upper part of the Choukomori Subcomplex changes to sandstone-dominant alternating sandstone and mudstone in this valley and in the Kogawa Valley. Black massive mudstone, millimeter-scale parallel-laminated mudstone, and sandstone-dominant alternating sandstone and mudstone crop out in the Toyomanegawa Valley. Cleavages are developed in all these facies. Fine- to coarse-grained brownish-gray sandstone is interbedded with gray to black massive mudstone in Otsuchi. These clastic rocks tend to be deformed near the western boundary of the Choukomori Subcomplex. Sandstone with rip-up clasts is found near the mouth of the Nagasawa Valley. The uppermost part of the subcomplex in this valley changes into mudstone overlain with the ribbon chert of the Shiraitotaki Subcomplex. Poorly sorted, coarse-grained, dark-gray to white sandstone with many rip-up clasts is exposed near the upper ends of the Kitakawamesawa and Karowazawa valleys, and in the middle to upper Sen'notairasawa Valley.

The Choukomori Subcomplex is patchily distributed on topographic highs on the southern slope of Mount Maekariyama, at the end of the Sakamotosawa-2 Valley, and in the middle of the O'shounaisawa Valley. Medium- to coarse-grained, light-gray to white massive sandstone crops out at elevations higher than 550 m near the upper end of Sakamotasawa-2 Valley. Alternating sandstone and mudstone are found on topographic highs north of the Yumenukihirasawa Valley.

Massive gray sandstone can be seen on the ridge south of the southern A valley of the Kaizawa Valley. Medium- to coarse-grained sandstone with rip-up clasts is found at elevations higher than 470 m in the southern B valley of the Kaizawa Valley. Outcrops of sandstone and mudstone are found at elevations ranging from 450 to 470 m on the ridge west of the southern B valley of the Kaizawa Valley. Sandstone with rip-up clasts is occasionally intercalated with 10-cm-mudstone beds at elevations higher than 450 m in the Kai'nouesawa Valley. Dark-gray to gray, millimeter-scale, parallel-laminated, medium- to coarse-grained sandstone with rip-up clasts is observable in the northern A valley of the Kai'nosawa Valley. Alternating medium- to coarse-grained sandstone with black rip-up clast, mudstone with sandy lamination, and massive sandstone crop out in the northern B valley of the Kai'nosawa Valley.

Generally, the Kotanichi Subcomplex strikes WNW to NNW and dips 25-60°W in the Kitanomatazawa, Shimochizawa, Kogawa, and Nagasawa valleys. This subcomplex occasionally strikes to E-W and dips southward at the upper end of the Kitanomatazawa Valley. In the middle to upper Sen'notairasawa Valley, the bedding of sandstone strikes N 45°W and dips 40°E.

Thickness : The apparent thickness of the Choukomori Subcomplex is 50 m on ridges among the Shimochizawa, Ohkawa, Nagasawa valleys and from 300 to 400 m in the western Toyomane-Kazawa area. The subcomplex attains a maximum apparent thickness of 1000 m in the upper Nagasawa Valley and exceeds 200 m in thickness in the northwestern Kawai area, although the upper boundary of the subcomplex has been completely eroded.

Contacts : The base boundary of the Choukomori Subcomplex is a fault that dips shallowly to the west ($<20°$) with a NNE-SSW strike and is associated with crushed chert and mudstone near the end of the Sakamotosawa-2 Valley.

Comparison : Sandstone of the Choukomori Subcomplex can be distinguished from sandstones of other subcomplexes by the presence of many mudstone rip-up clasts.

Fossils and age : No fossils are found in the Choukomori Subcomplex.

4.5.3. Shiraitotaki Subcomplex (new ; Sk)

Type locality : Near Shiraitotaki.

Definition : Ribbon chert sandwiched between the Choukomori and Yasomori Subcomplexes.

Lithology : This subcomplex consists mainly of white to gray ribbon chert.

Distributions : This subcomplex has limited exposure at topographic highs in the Toyomane-Kazawa area and in southernmost part of the southwest Moichi area. The base of the Shiraitotaki Subcomplex is roughly traceable from Toyomane-Kazawa to the southernmost part of the southwestern Moichi area at elevations ranging from 500 to 660 m. The top of the Shiraitotaki Subcomplex is also traceable

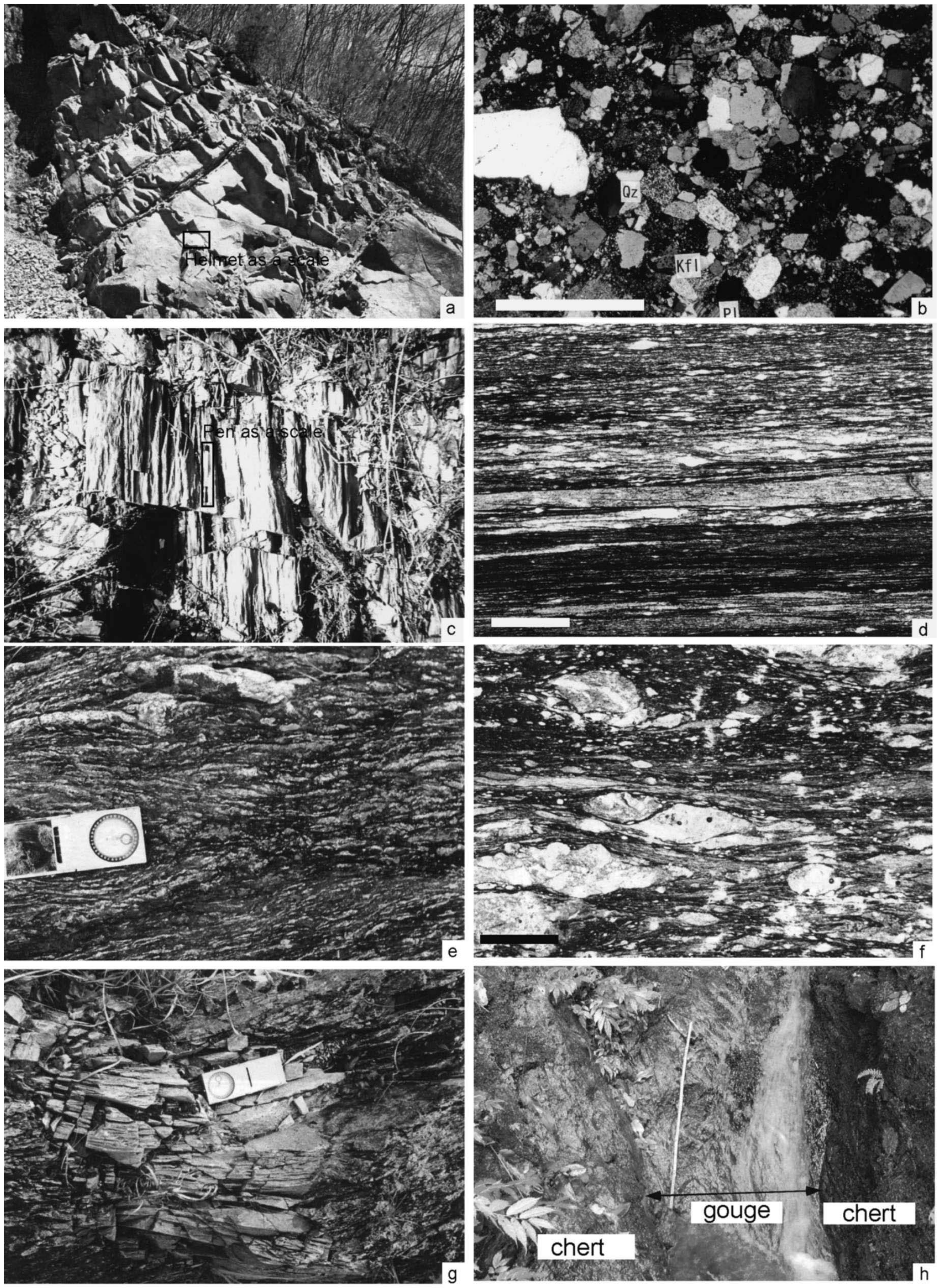


Figure 29. (a) Sandstone-dominant alternating sandstone and mudstone of the Choukomori Subcomplex in the Nekoezawa Valley. For scale, the size of the helmet is 30 cm. (b) Photomicrograph of sandstone from the Choukomori Subcomplex in the II branch of the Sakamotosawa Valley. Scale bar=0.1 mm. Qz : Quartz, Klf : K-feldspar, Pl : Plagioclase. (c) Well-developed cleavage in the mudstone of the Kirinai Subcomplex in the Kirinai No. 1 Bridge Valley. (d) Extraordinarily elongated mudstone grains of the Kirinai Subcomplex. Kirinai No. 6 Bridge Valley. Plane polarized light. Scale bar=1 mm. (e) Deformation of ribbon chert of the Komataguchi Subcomplex at Assenoguchi Bridge over the Kazawa River. For scale, the width of the clino-meter is 6.5 cm. (f) Microphotograph of slate of the Komataguchi Subcomplex. Scale bar=1 mm. (g) Cleavage in the porphyrite dike sheet exposed at Assenoguchi Bridge over the Kazawa River. For scale, the width of the clino-meter is 6.5 cm. (h) The Horochi Fault in the east IV branch of the Minamikawamesawa Valley.

at approximately 750 m elevation in these areas.

Main outcrops : Light-gray volcanic rocks at the base of the Shiraitotaki Subcomplex are exposed at elevations ranging from 500 to 540 m in the Tsubonezawa Valley. Recrystallized white to gray ribbon chert is exposed in the Kitanomatazawa and Minaminomatazawa valleys. Small outcrops of recrystallized white to dark-gray ribbon chert are scattered in the Shimochizawa Valley. Ribbon chert is also continuously distributed on the slope of the Kogawa Valley and on the topographic highs between Mount Mizunomibayama and Mount Takatakimori. In the southwestern Moichi area, the Shiraitotaki Subcomplex is observable in the Nagasawagawa, Kitakawamesawa, and Sen'notairasawa valleys, and around Minamikawame. Black ribbon chert is found at the end of the Nagasawagawa Valley. A 100-m-thick ribbon chert is observable in the Kitakawamesawa Valley, at the end of the Kitakawamesawa Valley, and at the end of the Sen'notairasawa Valley. Ribbon chert outcrops are found in northern ridges in Minamikawame. In the Kawai area, this subcomplex was only observed in the Nakanomatazawa Valley. One outcrop of massive black chert was found in the middle of the A valley in the Nakanomatazawa Valley and at elevations below 600 m on the ridge south of the A valley in the Nakanomatazawa Valley.

The strike of Shiraitotaki Subcomplex is between N-S to NW, and the dip is between 30°E and 45°W in the Kitanomatazawa and Minaminomatazawa valleys, at the end of the Nagasawagawa Valley, and on northern ridges in Minamikawame.

Thickness : Approximately 30 m.

Contacts : The base of the Shiraitotaki Subcomplex is probably in fault contact with the underlying Choukomori Subcomplex. The Shiraitotaki Subcomplex is in conformable contact with the overlying Yasomori Subcomplex.

Comparison : This subcomplex is distinguishable by tectonostratigraphic positions from other chert units, although this subcomplex also tends to be dominated by dark-gray to black ribbon chert.

Fossils and age : No fossils are found in the Shiraitotaki Subcomplex.

4.5.4. Yasomori Subcomplex (new ; Ys)

Type locality : The southern area of Mount Yasomori in the Toyomane-Kazawa area.

Definition : The Yasomori Subcomplex is defined by several sets of chert-clastics sequences above the Shiraitotaki Subcomplex. The upper boundary of the subcomplex is unknown due to erosion. The Yasomori Subcomplex could be further divided into several subcomplexes based on chert-clastics sets but is tentatively treated as a single subcomplex because of poor distributions caused by erosion.

Lithology : The basal part of the subcomplex is dominated by sandstone-dominant alternating light-gray to dark-gray, bluish-gray sandstone, and dark-gray mudstone. Sandstone predominates in the middle and upper parts with occasional occurrences of dark-gray chert blocks. The sandstone of the middle and upper parts is well-sorted, medium- to coarse-grained feldspathic arenite with occasional rip-up clasts.

Distribution : This subcomplex has limited exposures at topographic highs in the Toyomane-Kazawa area and in the southernmost part of the southwestern Moichi area. The middle to upper parts of the Yasomori Subcomplex are occasionally observed on ridges of the Kogawa, Shimochizawa, Ohkawa, and Nagasawagawa valleys.

Main outcrops : Well-sorted, medium- to coarse-grained, massive, dark-gray sandstone is exposed at the upper end of the Nagasawagawa Valley in the southwest Moichi area and along the road between Mount Karomori and the Oh'horazawa Valley. Sandstone is widely distributed on the ridges adjacent to branches of the Kitakawamesawa, Nagasawagawa, and Sen'notairasawa valleys. The bedding of the sandstone strikes N 10°E and dips 50°E in the upper end of the Nagasawagawa Valley, and N 57°W and 30°E along the road between Mount Karomori and the Oh'horazawa Valley.

Thickness : The thickness of the Yasomori Subcomplex ranges from 30 to 100 m in the Toyomane-Kazawa area, becoming thicker toward the north, up to 1100 m at the end of the Nagasawagawa Valley.

Contacts : The Yasomori Subcomplex conformably overlies the Shiraitotaki Subcomplex.

Comparison : The Yasomori Subcomplex is directly in contact with the Choukomori Subcomplex in many localities due to the absence of the Shiraitotaki Subcomplex. The sandstone of both subcomplexes is so similar that their boundary cannot be precisely determined in areas where the Shiraitotaki Subcomplex is missing.

Fossils and age : No fossils are found in the Yasomori Subcomplex.

4.6. Takatakimori Complex (new)

Historic review : The Takatakimori Complex was considered to be the eastern margin of the South Kitakami Belt (Yoshida and Katada, 1964) but was later separated from it because of lithologic differences. Now, the complex is treated as a western part of the North Kitakami Belt (Osawa, 1983). Otoh and Sasaki (2003) considered this subcomplex a mylonite belt.

Distribution and contacts : The Takatakimori Complex lies in an elongated fault-bounded belt between the South Kitakami Belt to the west, and the Tsugaruishi and Karomori Complexes to the east. The Kirinai and Komataguchi Subcomplexes are recognized in the Takatakimori Complex on the basis of their separate distributions and lithologic differences.

4.6.1. Kirinai Subcomplex (redefined ; Ki)

Author : Osawa (1983).

Type locality : The Kirinaisawa Valley.

Re-definition : This subcomplex is redefined by slaty rocks and alternating, extraordinarily elongated chert and slate, that are interbedded with thin basic tuff and sandstone (Figs. 29c, 29d). This subcomplex, as redefined here, is correlated with the upper part of the Tassobe-guchi Formation (Onuki, 1969) and the lower part of the Kirinai Formation (Osawa, 1983).

Lithology : The Kirinai Subcomplex includes relatively large elongated rock bodies of ribbon chert, sandy mudstone, and green-colored tuff. Thin layers of green-colored tuff, feldspathic wacke, and lithic wacke are occasionally found in the Kirinai Subcomplex. Phyllitic mudstone, chert, and intercalated tuff layers characterize the type locality of the Kirinai Subcomplex. The strike and dip of the phyllite planes are N16°-38°W and vertical. These planes are nearly parallel to the elongated direction of sandy mudstone and chert lenses. Chert and mudstone in many localities are marked by millimeter-scale laminations.

Distribution : This subcomplex is narrowly distributed along the boundary of the South Kitakami Belt in the southwestern part of the Kawai area.

Main outcrops : Mudstone, ribbon chert, massive chert, and sandstone are observable in the valleys north of the Kirinai No. 3 Bridge. Cleavage-developing mudstone dominates in the valley northwest of Kirinai village. Ribbon chert is also found in this valley. Cleavage-bearing mudstone with sandy mudstone and chert lenses, massive sandstone, alternating sandstone and mudstone, and ribbon chert are found in a valley near the Kirinai No. 6 Bridge. Slaty cleavage-bearing, alternating mudstone and chert are occasionally intercalated with green-colored tuff in a valley near Kirinai No. 1 Bridge. Cleavage-developing black mudstone and interbed millimeter- to centimeter-scale chert lenses are elongated in an N20°-30°W direction in the Nakanomatazawa Valley. This mudstone also yields siliceous mudstone and medium-grained massive sandstone.

The strike and dip of the bedding of the chert are N 20°W and 60°N, respectively, in the valleys north of the Kirinai No. 3 Bridge. The strike and dip of cleavage planes are N 15°W and 75°E in the valley northwest of Kirinai village, and N 20°-35°W and 75°-85°W in a valley near the Kirinai No. 1 Bridge.

Thickness : The apparent thickness of the Kirinai Subcomplex exceeds 3000 m.

Contacts : The Kirinai Subcomplex is in contact with the Karomori Complex by vertical faults.

Fossils and age : No fossils are found in the redefined Kirinai Subcomplex.

Comparison : The Kirinai Subcomplex is structurally similar to the Komataguchi Subcomplex, but we cannot confirm the relationship between them because of their isolated distributions.

4.6.2. Komataguchi Subcomplex (new ; Km)

Type locality : The roadside and riverside from Tozawa village to the meeting point of the Oshitatizawa Valley and Kazawa Valley in Otsuchi Town.

Definition : Phyllitic black mudstone associated with a small amount of blocks of sandstone, chert, and greenstones (Figs. 29e, 29f).

Lithology : This subcomplex consists mainly of phyllitic mudstone which occasionally includes millimeter- to centimeter-scale basaltic rock, chert, and sandstone blocks. The plane is oriented to a NNW strike and has a vertical dip. Volcanic rocks consist of olivine-augite-plagioclase basalt and ophitic basalt.

Distribution : This subcomplex is found in the western part of the Kazawa area.

Thickness : At least 400 m. The total thickness of the subcomplex is unknown because the western boundary has not yet been detected.

Contacts : The Komataguchi Subcomplex is in contact with the Karomori Complex by vertical faults.

Fossils and age : No fossils have been found in this subcomplex.

Comparison : The predominance of phyllitic mudstone easily distinguishes the Komataguchi Subcomplex from the Kitakawame and Tsugaruishi Complexes.

4.7. Igneous rocks

4.7.1. Dikes

Porphyrite and plagioclase-porphyrite dikes dominate throughout the study area. Plagioclase-porphyrite dikes in the Toyomane-Kazawa area intrude in the Kuzumaki-Kamaishi Subbelt in a NNW-NNE direction and are generally traceable up to several to tens of meters. Plagioclase porphyrite (1-10 m thick) is characterized by large white plagioclase phenocrysts (approximately 3-5 cm in length) and by a brownish-gray matrix. Plagioclase porphyrite dikes in the southwestern Moichi area were observed only in the Nagasawagawa and Kitakawamesawa valleys. Porphyrite dikes are marked by slaty cleavages at the mouth of Asse-no-sawa Valley ; they intrude in a N 3°E trend in the Komataguchi Subcomplex in the Toyomane-Kazawa area, where cleavages strike N 27°W (Fig. 29g). Greenish-gray to gray porphyrite dikes are found throughout the southwest Moichi area. These dikes are thermally metamorphosed by granitic rocks and have small hornblende and pyroxene phenocrysts and plagioclase groundmass. Most phenocrystic hornblendes and pyroxene are altered by calcite. The groundmass of porphyrite occasionally contains pyroxene-laths.

Variegated light-gray, light-greenish blue, very light-gray, and gray hornblende-dolerite, dacite, dioritic porphyrite, and plagioclase porphyrite intrude in a NNW-NNE direction in the Kuranosawa, Nawauchisawa, Shikauchisawa, and Koshika’uchisawa valleys, and along the Heigawa River of the northwestern Moichi area. These dikes are several to tens of meters thick.

4.7.2. Early Cretaceous plutonic rocks

The Nenekomori Pluton (Ishii *et al.*, 1956) is distributed on and around Mount Nenekomori in the Kawai area, west of the Ohsawa Valley, and the upper reaches of the Uchinosawa Valley in the southwestern Moichi area. A small granitic body crops out on the riverbed of the Heigawa River, east of Kawai. The Maekariyama Pluton (Ishii *et al.,* 1956) is comprised of two separate bodies. The east body is distributed on the eastern slope of Mount Maekariyama, and the west body is distributed on the western-northwestern slope of Mount Maekariyama and crops out in the Kitsubushisawa Valley. The Maekariyama Pluton is 60% plagioclase, 20% hornblende, 10% quartz, and 3% biotite. The plagioclase is characterized by a zonal structure. The Miyako Pluton intrudes in the eastern part of the southeastern Moichi area.

4.7.3. Other igneous rocks after the Oshima Orogeny

The Oshima Orogeny is an Early Cretaceous tectonic event, causing the angular unconformity between the Hauterivian - Aptian Miyako Group and the underlying rocks in the Kitakami Massif associated with accretion of the North Kitakami Belt to the South Kitakami Belt, formation of N-S trending compressional folds with slaty cleavage, sinistral strike-slip movement along the NNW-SSE directional faults associated with anticlockwise rotation of compression axis and intrusion of the Early Cretacoues plutonic rocks (Kanisawa and Ehiro, 1986).

A group of the Oguni Dacite intrudes into the Kirinai Subcomplex. Outcrops of a similar dacite are scattered in the northwestern Moichi and Kawai areas. Welded tuff is observable at 480 m elevation in the upper end of the Kakunosawa Valley and on a ridge northeast of the East Maekariyama Pluton. The tuff has crystal vitric laths with a flow structure.

5. Geologic structures

5.1. Fault systems (Figs. 6-8)

5.1.1. NW-trending vertical faults

Northwest-trending vertical faults are mainly distributed between Fukushi in the southeastern Moichi area and the mouth of the Kuranosawa Valley in the northwestern Moichi area. The Warabinosawa and Horochi faults are major NW-trending vertical faults in the study area (Fig. 7). The Warabinosawa Fault and associated faults form several NW-SW trending geographic lineaments around the Warabinosawa Valley. The Warabinosawa Fault is 20 km long from the south of the Toyomane-Kazawa area to the north of the northwest Moichi area. It crops out along a woodland road in a branch of the Warabinosawa Valley where a consolidated, 100-m-thick gouge zone of crushed mudstone blocks (ca. 20 cm in diameter) is observed. The strike and dip of the fault surface are N 50°W and nearly vertical. The Warabinosawa Fault is traceable to other areas. This fault does not crop out along the woodland road to the non-operational Moichi Ore Mine, but a high-angle boundary between both subcomplexes is presumed based on lithologic distributions in valleys and on ridges and slopes. The Warabinosawa Fault is occasionally associated with other smaller faults. A consolidated gouge zone with crushed chert blocks (approximately 40 cm) crops out at 800 m in elevation southeast of the road from Moichi Ore Mine, and crushed mudstone continuously crops out along NW-trending branches of the Hosogoe Valley. Other small faults associated with the Warabinosawa Fault are exposed along the road in the upper Warabinosawa Valley.

The Horochi Fault (Fig. 29h) parallel to the Warabinosawa Fault bounds the Nagaiwamori Complex from the Moichi and Tanesashi Complexes, although this fault does not make lineaments in this area. The Nagaiwamori Complex is in contact with the Tanesashi Complex by this fault, which is associated with a 100-m-thick gouge zone in the Shoudonosawa Valley. The movement directions of these NW-trending faults are unknown.

A significant fault, the Kirinai Fault, is bounded between the Takatakimori Complex and the Karomori Complex south of the Kawai area (Fig. 8) and west of the Toyomane-Kazawa area (Figs. 6, 7). The strike of this fault changes from a NNW direction in the Kawai area to a NW direction in the Toyomane-Kazawa area. The fault may be separated by an E°W trending fault that extends from north of Etsunagi (Fig. 4).

5.1.2. NNE-trending vertical faults

North-northeast-trending faults and probable associated faults are recognized in the Kawai and northwestern Moichi areas (Fig. 8). The distributed altitudes of the same subcomplex of the Karomori Complex indicate that these faults moved vertically. The Saike, Nakanomata, and Kariya faults cut the NW-trending Horochi, Warabinosawa, and Kirinai faults, as well as the Nenekomori and Maekariyama plutons.

5.2. Mappable structure

The Kuzumaki-Kamaishi Subbelt had been considered a vertical structure until Okami (1990) noted the existence of shallowly tilting structures. As shown in Figure 30, the mappable structures appear vertical if only the bottoms of valleys are investigated (Figs. 30a, 30b). Shallowly dipping structures are detailed by the altitudes of their boundaries. The base of the Kotanichi Subcomplex in the northwestern Moichi area dips to the west between 5-25° (Fig. 31). Its base crops out at elevations ranging from 500 to 550 m in the Kitakawame Valley, from 530 to 600 m in the Karowazawa Valley, from 570 to 650 m in a valley 800 m east of the Karosawa Valley, and at an elevation of 650 m in another valley 1000 m east of the valley, respectively. The Kotanichi Subcomplex dips very shallowly 5° to the west. This structure is in accord with the topographic distributions of the Shiraitotaki Subcomplex in this area as well.

In the eastern part of the northwestern Moichi area, the boundary between the Furuyadomori and Kotanichi Subcomplexes tilts relatively eastward and is traceable up to 900 m elevation. The Furuyadomori Subcomplex attains a maximum thickness of 150 m in the southeastern part of the northwestern Moichi area. This subcomplex disappears north and west of the northwestern Moichi area. Instead, the Fukushi Subcomplex is in direct contact with the Kotanichi Subcomplex in this area.

The mappable structure of the Komatsugura Subcomplex is recognizable by the distributions of the ribbon chert of the middle Komatsugura Subcomplex. The base of this chert is located at 180 m elevation in both the north I and north II branches of the Komatsugurasawa Valley and at 160 m elevation on the ridge between the north I and II branches of the Komatsugurasawa Valley (Fig. 7). The strike and dip of the base of the ribbon chert are N 40°W and 30°W.

Low-angle structures at a mappable scale are also recognized in the Kitakawame Complex. The ribbon chert of the Minamikawame Subcomplex crops out as cliffs several tens of meters in height in many outcrops in the southeastern Moichi area. The mappable structure is easily recognized along the middle Nagasawagawa Valley. The Minamikawame Subcomplex exposes at elevations ranging from

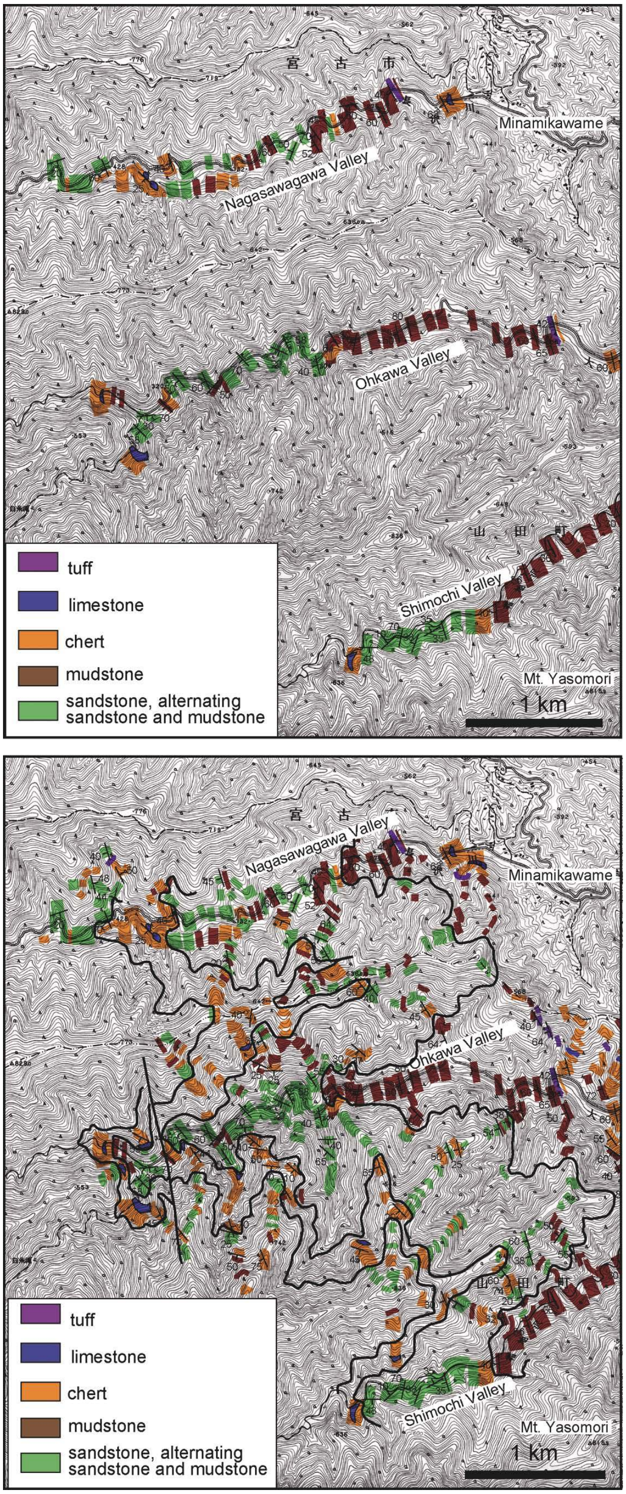


Figure 30. Exposures of lithologies. If only valley bottoms are investigated, the mappable structures look like vertical distributions, as shown in Figure 30 (upper). Detailed investigation results of the same area are shown in Figure 30 (lower), which shows the mappable horizontal distributions.

200 to 360 m in the south branch of the Nagasawagawa River, at elevations ranging from 200 to 350 m in the northwest branch of the Nagasawagawa River, and at 70 m along the Nagasawagawa Valley road. The strike and dip of the boundary between the Minamikawame and Nagasawagawa Subcomplexes are N 28°W and 20°W. The Minamikawame Subcomplex is traceable in similar altitudes in the Minamikawame, Kitakawame, and Komatsugurasawa valleys. The bedding planes of the ribbon chert of the Minamikawame Subcomplex are usually parallel to the basal boundary of the subcomplex. The bedding of the ribbon chert in the Komatsugurasawa Valley typically has a N 30°E strike and 30°W dip.

On the other hand, chert and mudstone in the Nagaiwamori and Shimochi Subcomplexes usually have a vertical, northwest trend in the southwest Moichi area. The boundaries between ribbon chert and mudstone show transitional change, and their facies suggest that closed folds developed in the Kitakawame Complex. The Kitakawame Complex is also repeated by branched faults from the Warabinosawa Fault.

Previously published geological maps of the study area show different fault patterns. Yoshida and Katada (1984) illustrated several faults with a northwest trend, which erroneously joined the Kitakawame Fault with the Warabinosawa and Horochi faults in the same area. Our survey did not show other NW-trending faults, including the Kitanomatazawa Fault. Previous geologic maps also indicate NNW-trending faults such as the Horochi, Warabinosawa, and Kirinai faults (Iwate Prefecture, 1954 ; Yoshida and Katada, 1984) ; of these, the Kariya Fault (Yoshida and Katada, 1986) is mapped in a similar location on our geologic map. However, our survey did not indicate the presence of other vertical faults, including the Haratai Fault, in the area studied.

5.3. Intrastructure of outcrops : an example of the Fukushi Subcomplex

The mappable structure of the Tsugaruishi Complex is characterized by low-angle structures. In contrast, the intrastructure of the subcomplexes is marked by high-angle bedding planes. This contradiction is explained by intrafolial folding, which was revealed by analysis of the intrastructure of the Fukushi Subcomplex in the northwestern Moichi area. The Fukushi Subcomplex of the Tsugaruishi Complex is dominated by grading beddings from very fine-grained sandstone to mudstone, and thus it is appropriate to consider the intrastructure of this subcomplex.

The bedding of the Fukushi Subcomplex at visible outcrops in the south branch of the Hon'munesawa Valley has a NW-NNW strike and 70-80°W dip (Fig. 32a). The poles of these bedding planes plot on the lower hemisphere of the stereonet to high-angle portions. Bedding planes at two points show a dip of 40° to the east, and those at 18 points show upward-fining sequences to the west ; the remaining two points show upward-fining sequences to the east. Subsequently, the Fukushi Subcomplex in the south branch of the Hon'munesawa Valley (Fig. 33a) generally faces to the west. Based on the stereonet results, these folds are asymmetric, isoclinial to closed folds with a half wavelength

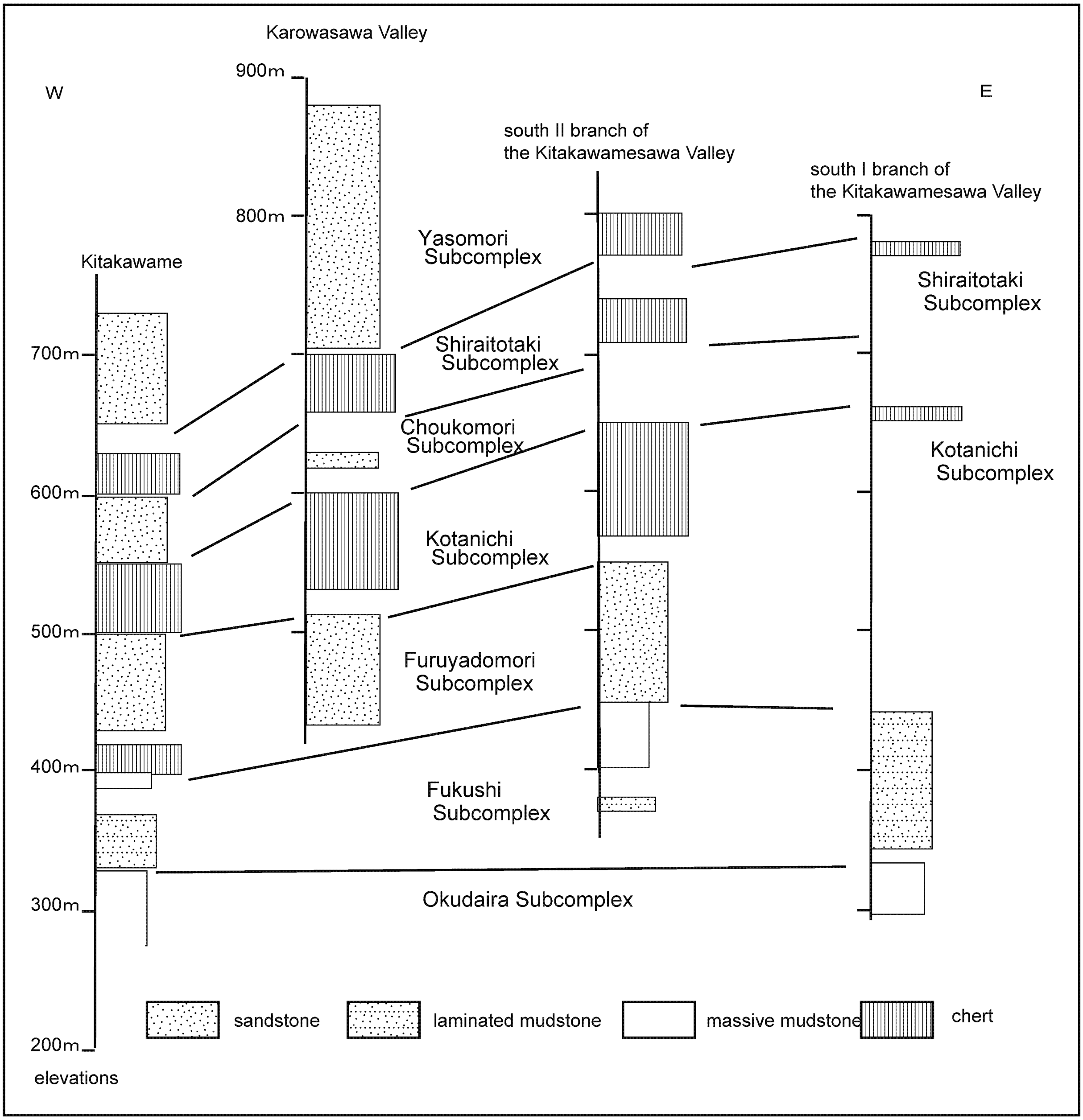


Figure 31. Schematic elevation and stratigraphic division diagram in the northwestern Moichi area.

of 30–80 m, in which the westernly dipping limbs are wider than the easternaly dipping limbs, fold axial planes tilt to the west, and the fold axis plunges gently to the northwest.

The Fukushi Subcomplex in the west branches of the Maekarisawa Valley (Fig. 32b) dips to the west at 25 points and to the east at 7 points. The poles of bedding planes on the lower hemisphere of the stereonet plot at high-angle portions. Eleven points have upward-fining sequences to the west, while two points have upward-fining to the east; these points are in the west branches of the Maekarisawa Valley where the Fukushi Subcomplex generally faces to the west. These folds (Fig. 32b) also have asymmetric, isoclinal, or closed folding, with a half-wavelength of 30 m; the westernly dipping limbs are longer than easternaly dipping limbs, the fold axial planes tilt to the west, and the fold axis strikes NW.

Intrafolial folds of the Fukushi Subcomplex in the Nawauchisawa Valley (Fig. 32c) are similar to those in the west branch of the Hon'munesawa Valley and west branches of the Maekarisawa Valley. The bedding planes of the Fukushi Subcomplex generally strike N 30°–50°W and dip 60°–80° W at 15 points along the Kuranosawa woodland road in the Nawauchisawa Valley. The poles of the bedding planes on the stereonet plot at high-angle portions. Upward-fining

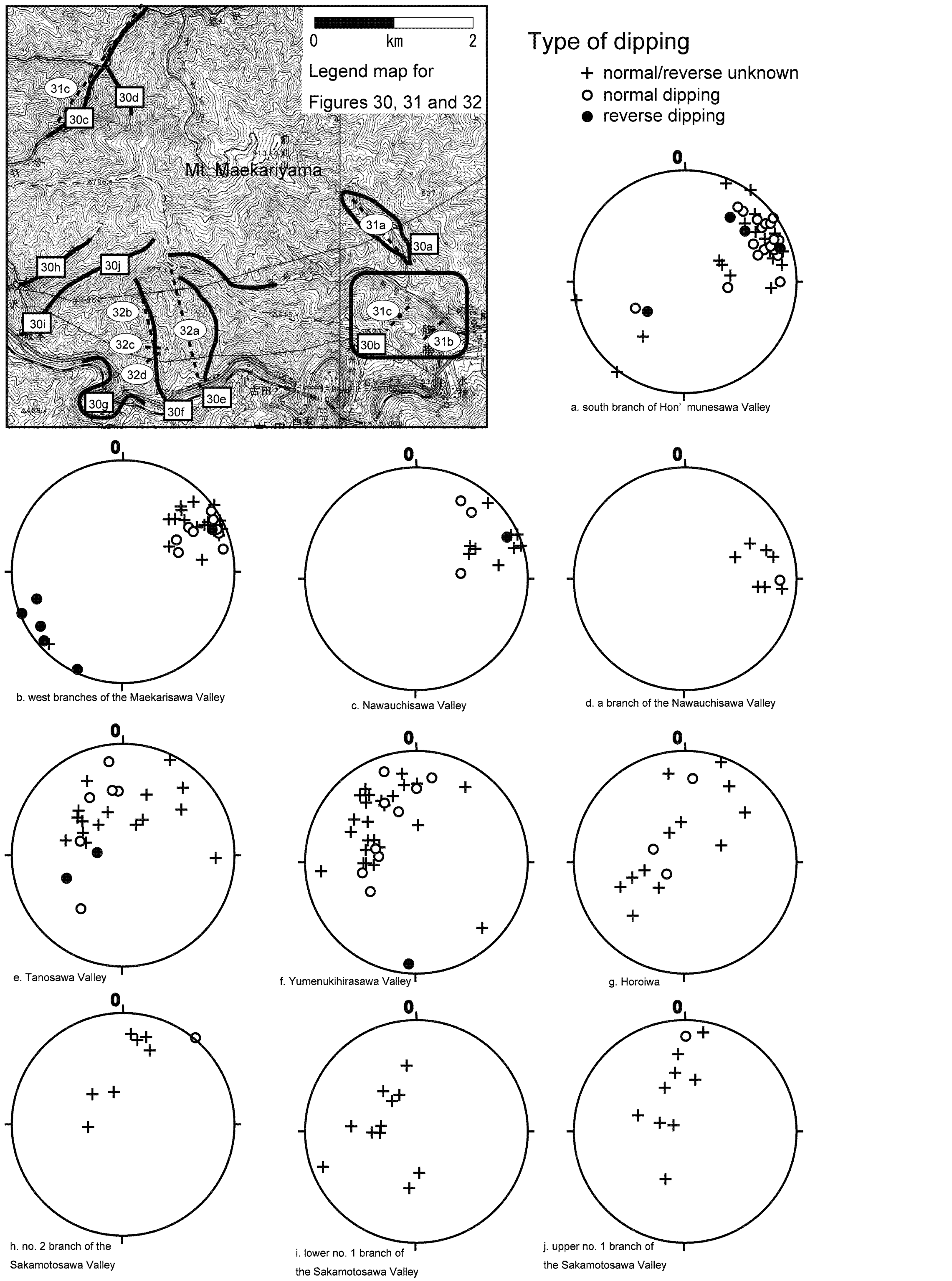


Figure 32. Bedding planes of the laminated mudstone of the Fukushi Subcomplex in the northwestern Moichi area. All planes on equal area stereonets are plotted as poles on the lower hemisphere.

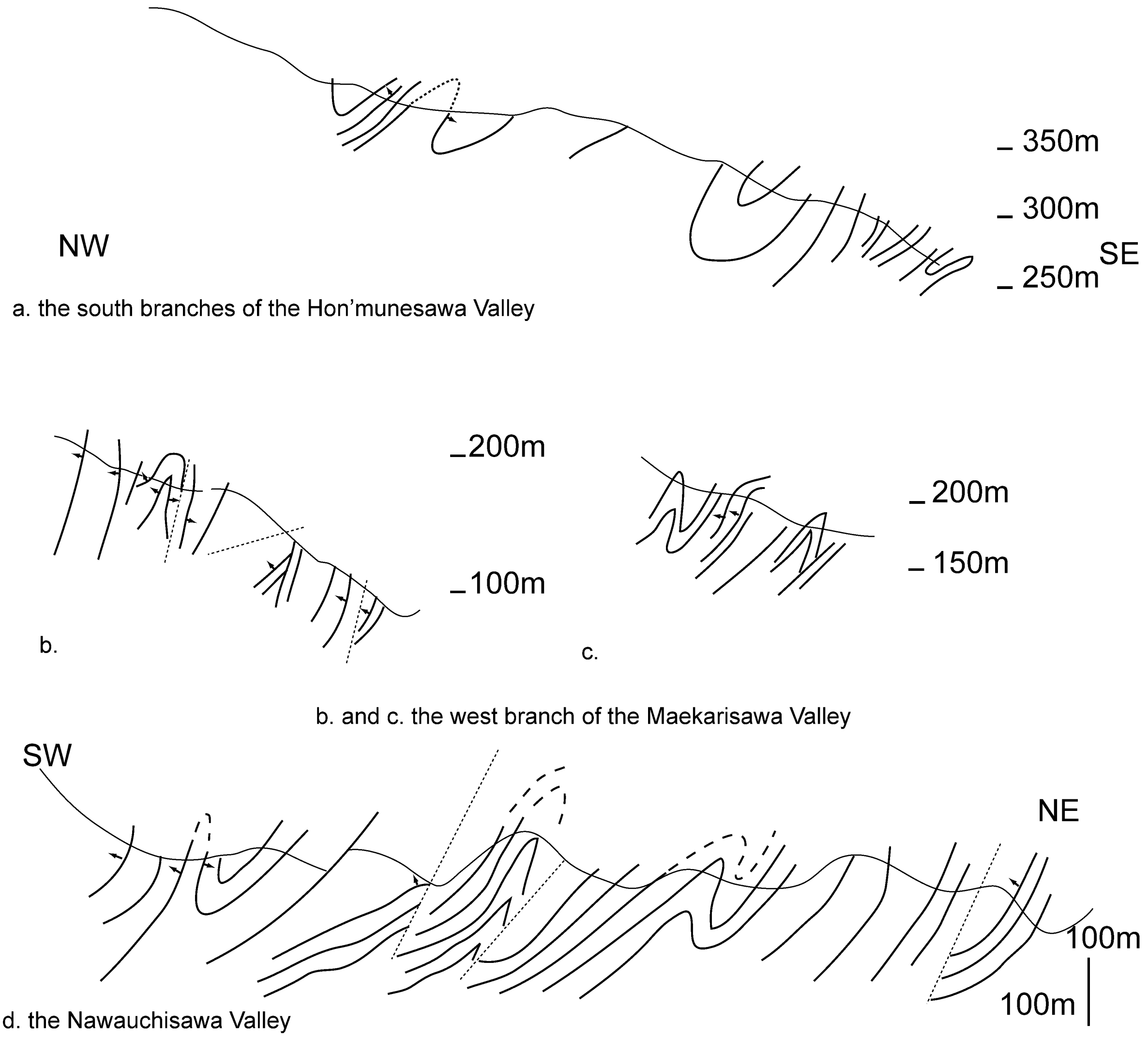


Figure 33. Geologic cross-sections of the Fukushi Subcomplex, showing intrafolial folding with normal / reverse dipping (black arrows). The sectioned lines are shown in Figure 32.

sequences to the west are recognized at four points, and those to the east are found at one point, suggesting that the Fukushi Subcomplex in the Nawauchisawa Valley generally faces to the west (Fig. 32c). These folds are asymmetric, isoclinal, or closed folds, with a half-wavelength of 50-100 m. Westernly dipping limbs are longer than the easternaly dipping limbs, and fold axis planes dip to west at a high angle.

The bedding planes of the Fukushi Subcomplex in a branch of the Nawauchisawa Valley (Fig. 32d) generally strike NNW and dip 40°-75°W at eight points. The poles of bedding planes at these points are plotted in a limited portion on the stereonet. Although the bedding plane at only one point faces west, the folds in the branch of the Nawauchisawa Valley are considered to have similar patterns to those in the Nawauchisawa Valley.

The poles of bedding planes of the Fukushi Subcomplex at 24 points in the Tanosawa Valley (Fig. 32e) are plotted on a girdle-like band on the lower hemisphere of the stereonet. Although upward-fining sequences to the south, to the west, to the east, and to the north are recognized at four, two, one, and one points in this valley, respectively, the Fukushi Subcomplex generally faces south in this valley (Fig. 34a) but occasionally shows wavy fold systems that face to the north and east.

The poles of the bedding planes of the Fukushi Subcomplex at 34 points in the Shimonosawa Valley (Fig. 32f) also plot on a girdle-like band on the stereonet. Upward-fining sequences to the south are found at nine points and those to the east are found at four points in the Shimonosawa Valley where the Fukushi Subcomplex faces dominantly to the south. The interlimb angle of the folds is occasionally so wide that the half-wavelength of the folds ranges from 50 to 100 m (Fig. 34b).

The Fukushi Subcomplex strikes E-W and dips 75°-90° to the south at nine points in Horoiwa (Fig. 32g). Upward-

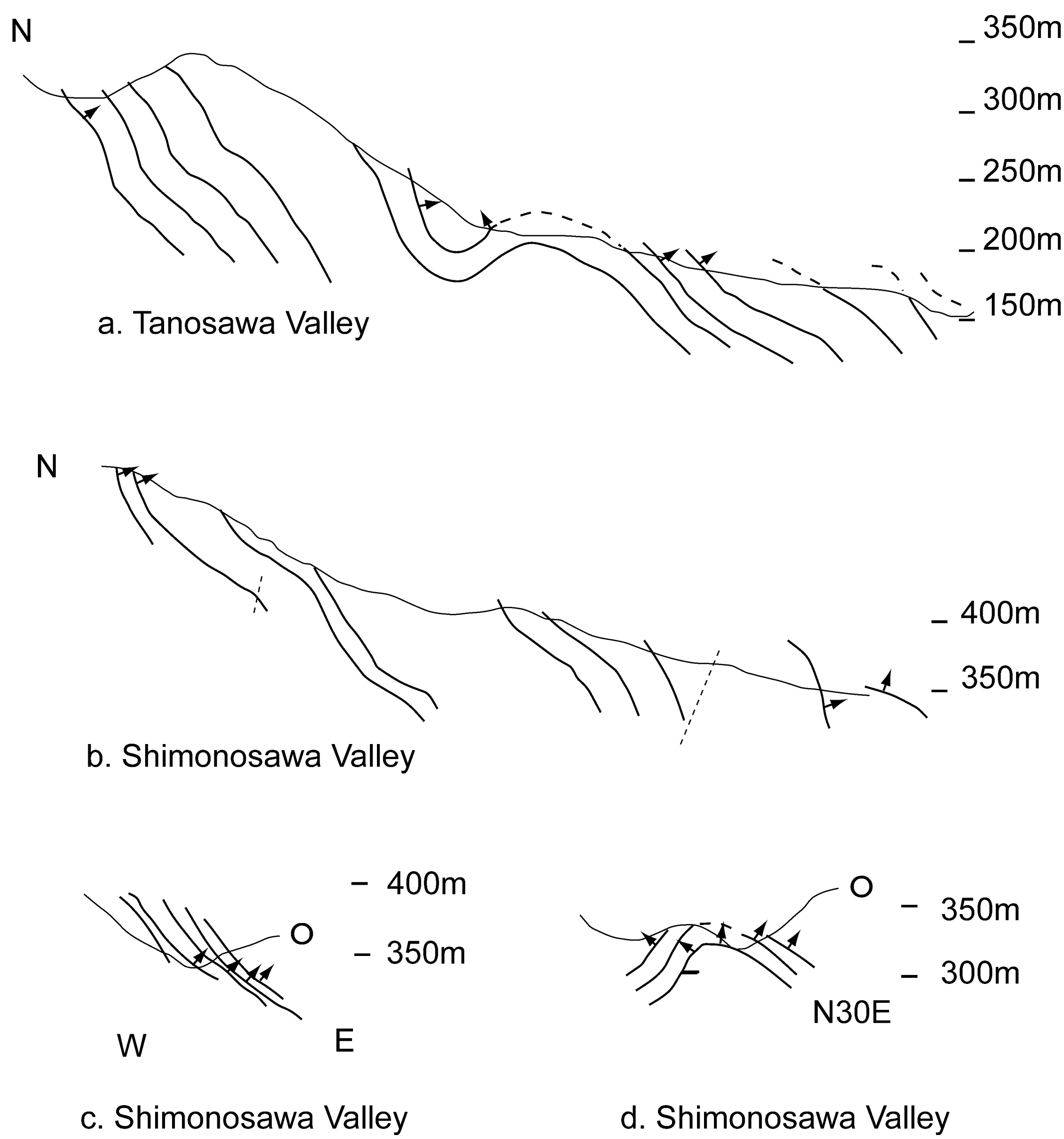


Figure 34. Geologic cross-sections of the Fukushi Subcomplex, showing intrafolial folding with normal / reverse dipping (black arrows). The sectioned lines are shown in Figure 32.

fining sequences of the subcomplex to the south occur at three points and those to the north at one point in Horoiwa. These data indicate that subvertical fold systems face south and the interlimb angles tend to be open (Fig. 34c).

The poles of the bedding planes at eight points in the No. 2 branch of the Sakamotosawa Valley (Fig. 32h) are plotted in a similar portion to those of the bedding planes in the Tanosawa and Shimonosawa valleys. An upward-fining sequence of the Fukushi Subcomplex is recognized at one point. Bedding planes at 12 points in the lower No. 1 branch of the Sakamotosawa Valley (Fig. 32i) commonly dip to the east. The bedding planes of the Fukushi Subcomplex at 10 points in the upper part of the No. 1 branch of the Sakamotosawa Valley (Fig. 32j) show variable dips and strikes creating girdle-like distributions, in which the folds have an E-W trending fold axis. An upward-fining sequence faces south at one point in the upper part of the No. 1 branch of the Sakamotosawa Valley. Bedding planes of the Fukushi Subcomplex at 15 points in the Yumenukihirasawa Valley have variable dips and strikes. Upward-fining sequences of the Fukushi Subcomplex face east at two points and south at one point.

As shown above, the intrastructure of the Fukushi Subcomplex differs from the mappable distributions of this subcomplex because of the short-wavelength intrafolial folding systems. Furthermore, the folding styles in the northwestern Moichi area can be categorized into northeast and southwest regions. The northeast region covers the south branch of the Hon'munesawa Valley and branches of the Maekarisawa Valley and Nawauchisawa Valley in the

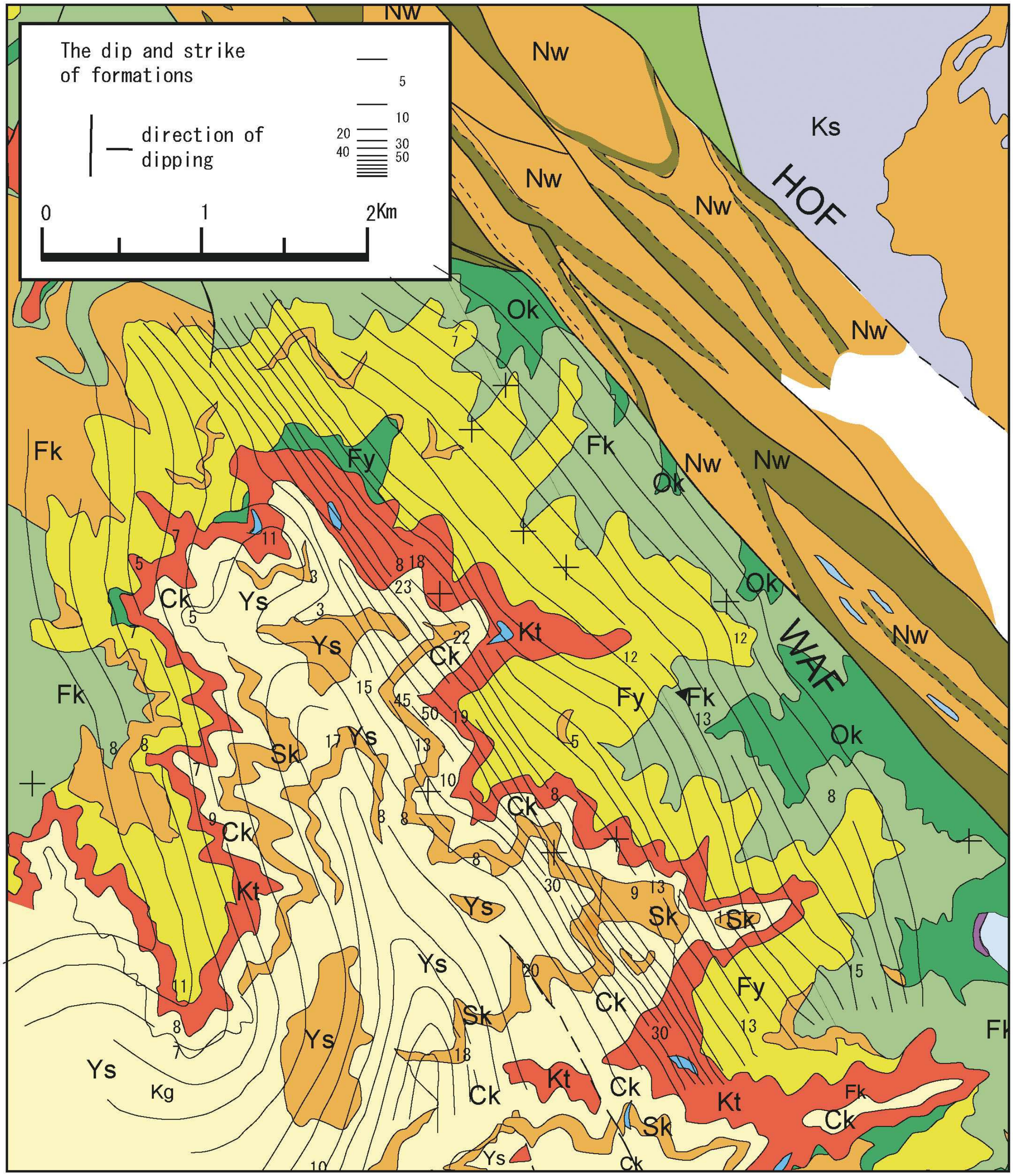


Figure 35. Formline map in the southwestern Moichi area.

eastern part of the northwestern Moichi area. The southwest region is in the Tanosawa Valley, the Shimonosawa Valley, branches of the Sakamotosawa Valley, Horoiwa, Yumenukihirasawa Valley, and the western part of the northwestern Moichi area.

In the northeastern region, the bedding planes of the Fukushi Subcomplex tend to have northwest strike directions and subvertical dips, and the poles of bedding planes tend to plot in a similar portion of the lower hemisphere of the stereonets. Upward-fining structures generally face west, developing asymmetric, isoclinal or closed folds with a long westernly dipping limb and narrow interlimb angles. In the southwestern region, the bedding planes of the Fukushi Subcomplex tend to have variable dips and strikes, but upward-fining sequences generally face to the south. This subcomplex is occasionally folded with a half-wavelength of

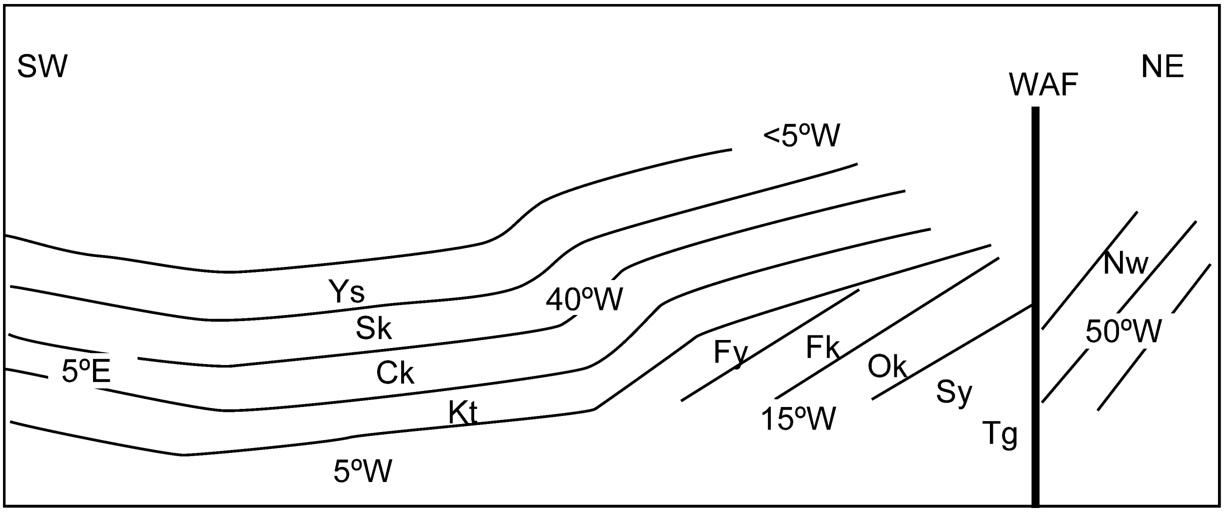


Figure 36. Schematic cross-section of the Karomori, Tsugaruishi, and Kitakawame Complexes in the southwestern Moichi area. Abbreviations are shown in Figure 5.

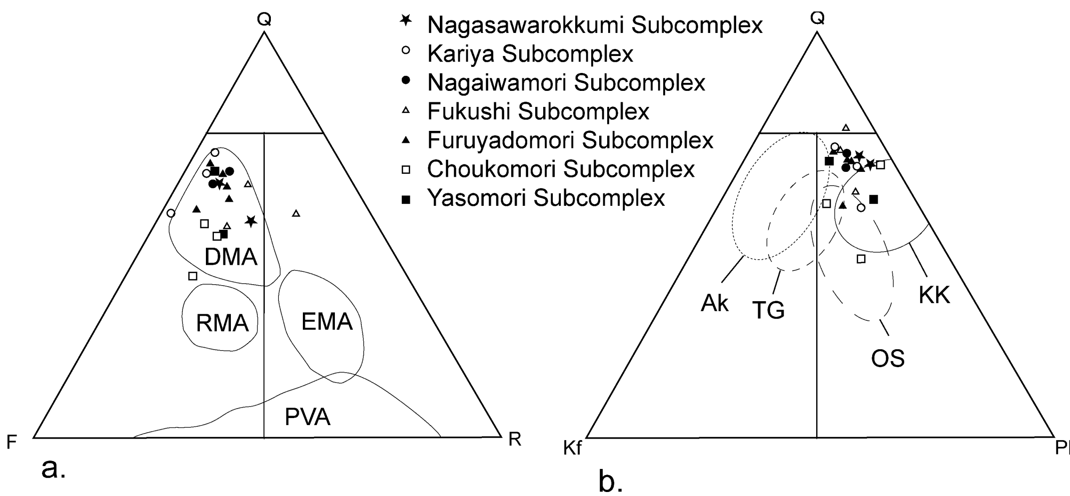


Figure 37. (a) The Q-R-F diagram for discrimination of the arc provenance type in the Japanese Islands by Kumon *et al.* (1992, 2000). (b) The Q-KF-PL diagram for discrimination of the Kuzumaki-Kamaishi (KK) and Akka-Tanohata subbelts (Ak) of Okami *et al.* (1992), with additional data on the Togano Group of the southern Chichibu Belt (TG) and the Oshima Belt (OS). Abbreviations : DMA : Dissected magmatic arc, RMA : Renewed magmatic arc, EMA : Evolved and mature magmatic arc, PVA : Primitive volcanic arc, Q : total quartz (monocrystalline and polycrystalline quartz), F : total feldspar, R : all rock fragments, Kf : K-feldspar, Pl : plagioclase.

50-100 m and faces to the east, west, and north. These differences between both regions, however, are considered to represent transitional change due to the lack of significant tectonic gaps between the regions.

These intraformational structures are apparently cut by subcomplex boundaries, suggesting that the intrafolial folding of the Fukushi Subcomplex formed prior to the development of boundaries between the subcomplexes.

5.4. Synforms and antiforms in the southwestern Moichi area

Low-angle structures of the Tsugaruishi and Karomori Complexes are deformed by large synform and antiform structures in the southwestern Moichi area (Fig. 35) and where the formline map in this area generally shows a strike of NNW-NW and a dip of 10-15°W. A relatively high-angle structure reaching 30° dipping to the west is present in a northwest trend from the upper reaches of the Kitakawame Valley to the Nagasawagawa Valley. Adjacent to the west of this high-angle zone, a shallowly tilted area develops to the east. In the eastern Sen'notairasawa Valley, the Karomori Complex shallowly dips 10° to the west, whereas the Karomori Complex shallowly tilts 10° to the east. These trends reveal the presence of one antiform and two synform folds in the southwestern Moichi area. An asymmetric synform with a high-angle westernly dipping limb develops a

NW-trending fold axis, plunges SSW, has a fold axis plane dipping 10–20° to the west, and shows an interlimb angle of 140–160° in the east of the southwestern Moichi area. This synform gradually becomes tight around the non-operational Haigura Ore Mine, reaching 130° at the higher interlimb angle. Another synform is recognized in the west of the southwestern Moichi area. This synform has a north trend, upright fold, and interlimb angle of 160°. An antiform is presumed to be present from the upper reaches of the Nagasawa River to the Heigawa River.

Based on the formline map, the Karomori Complex shows stepwise dips of 50°W, 0–15°W, 40°W, 5°W, and 5°E from the east to the west of the southwestern Moichi area (Fig. 36). On the other hand, the Tsugaruishi Complex beneath the horizontal part of the Karomori Complex dips 15° to the west, suggesting that the Tsugaruishi Complex is a separate unit. The formline map for the western slope of Mount Maekariyama indicates WNW-trending antiform and synform structures. These antiform and synform interlimb angles are approximately 150° and their half-wavelengths range from 250 to 500 m.

6. Petrology

6.1. Clastic rocks

The Kuzumaki-Kamaishi Subbelt differs from the Akka-Tanohata Subbelt by the dominance of plagioclase- and volcanic-clastic-rich sandstone (Okami *et al.*, 1992). This section describes the provenance of sandstones of the Kuzumaki-Kamaishi Subbelt. Samples were collected from the Fukushi (four samples), Furuyadomori (four samples), Choukomori (three samples), Yasomori (two samples), and Nagaiwamori (two samples) Subcomplexes. Thin sections were stained with sodium cobaltinitride (yellow stained after K-feldspar) and amaranth (pink stain after calcium plagioclase) after etching with concentrated hydrofluoric acid (Bailey and Stevens, 1960). We followed the Gazzi-Dickinson method of point counting, and counted 500 points of sand grains for each thin section (Table 2). The data were plotted on a quartz, feldspar, and lithic (Q-F-R) diagram to determine their provenance in some island arcs, as proposed by Kumon *et al.* (1992, 2000 ; Fig. 37a), and on a quartz, K-feldspar, plagioclase (Q-KF-PL) diagram to discriminate the Kuzumaki-Kamaishi and Akka-Tanohata subbelts shown by Okami *et al.* (1992 ; Fig. 37b).

The sandstones are generally classified as feldspathic wacke in excess of 15% matrix, although one sample from the Fukushi Subcomplex falls into the lithic wacke category based on Okada's classification (Okada, 1971). The sandstones are very fine- to medium-grained and well sorted with angular grains. Abundant quartz, plagioclase, and minor K-feldspars and chert fragments are also found. Quartz includes 13–31% monocrystalline quartz, including some grains that exhibit undulose extinction. Polycrystalline quartz (3–12%) is relatively minor compared with monocrystalline quartz. The total amount of feldspar ranges from 13 to 40% and consists mainly of plagioclase (10–22%). The K-feldspar (3–12%) includes sanidine and microperthite. Lithic fragments consist of chert, subordinate shale patches,

Table 2. Modal composition of the representative sandstones based on the Gassi-Dickinson method.

Compositions										Sandstone	Grain Size	Sucomplex	Locality
MQz	PQz	K-fel	Pl.	Va,Vi	Chert	Ot	H.M.	S.M.	Mtx	Type	Max (mm)		
12.6	27.0	5.8	9.8	0.0	3.2	0.0	0.0	2.8	38.8	arenite	1.3	Kariya Sucomplex	Kedamonosawa Valley
30.0	17.8	5.0	17.6	0.0	2.8	1.0	0.0	2.4	23.4	wacke	1.0	Kariya Sucomplex	Kuranosawa Valley
14.0	21.6	7.8	18.6	0.0	0.8	0.8	0.4	0.6	35.4	wacke	1.5	Kariya Sucomplex	Shoudonosawa Valley
23.6	22.6	7.0	15.4	1.2	2.0	2.0	0.2	9.4	16.6	wacke	1.0	Nagaiwamori Sucomplex	Shounaisawa Valley
20.4	20.2	5.2	11.0	0.6	4.6	1.2	1.2	3.2	32.4	wacke	2.0	Nagaiwamori Sucomplex	Shoukanaisawa Valley
24.6	16.4	3.0	9.8	1.2	11.2	7.8	0.0	3.4	22.6	wacke	4.0	Fukushi Sucomplex	Shimonosawa Valley
16.0	32.0	5.4	11.4	3.4	6.2	3.2	0.6	4.0	23.4	wacke	0.8	Fukushi Sucomplex	Shimonosawa Valley
19.0	22.6	8.0	17.6	1.6	4.8	6.6	0.8	1.4	17.6	wacke	1.8	Fukushi Sucomplex	Tanosawa Valley
13.4	25.2	4.6	12.6	0.0	5.4	0.8	0.0	1.4	36.6	wacke	2.3	Furuyadomori Sucomplex	Yumenukihirasawa Valley
16.0	27.4	6.4	11.4	0.2	2.4	3.0	0.2	1.8	31.2	wacke	1.9	Furuyadomori Sucomplex	Yumenukihirasawa Valley
21.8	26.6	6.2	14.8	0.6	1.8	1.0	0.2	3.2	23.8	wacke	0.3	Furuyadomori Sucomplex	Yumenukihirasawa Valley
12.4	20.4	10.4	12.6	2.8	5.6	0.4	0.4	1.4	33.6	arenite	1.0	Choukomori Sucomplex	a branch of No.2 Sakamotozawa Valley
18.8	9.4	11.6	19.4	1.8	2.0	6.2	0.0	2.8	28.0	arenite	1.8	Choukomori Sucomplex	a branch of No.2 Sakamotozawa Valley
22.4	12.6	11.8	12.8	3.6	1.6	2.0	0.6	5.2	27.4	wacke	1.3	Choukomori Sucomplex	a branch of No.2 Sakamotozawa Valley
24.6	22.8	4.4	15.8	1.4	3.2	1.2	0.0	4.0	22.6	wacke	0.5	Nagasawagawa Sucomplex	a branch of the Ushibushi Valley
30.8	7.2	3.2	15.2	0.6	2.2	11.8	0.2	3.0	25.8	arenite	3.0	Ushibushi Sucomplex	Mt. Tanesashi
28.8	13.0	11.4	19.6	2.4	1.6	0.8	0.2	3.4	18.8	arenite	2.0	Furuyadomori Sucomplex	a valley east of Futta
27.8	17.6	5.4	16.4	1.2	3.4	4.2	0.0	0.4	23.6	wacke	1.3	Furuyadomori Sucomplex	a branch of the Warabinosawa Valley
24.0	26.0	9.4	13.0	0.6	2.4	1.6	0.0	2.0	21.0	wacke	1.0	Yasomori Sucomplex	Nagasawagawa River
24.2	17.6	5.8	22.4	1.6	2.2	9.4	0.0	0.0	16.8	wacke	3.8	Yasomori Sucomplex	Kitakawamezawa Valley

MQz : monocrystalline quartz, PQz : polycrystalline quartz, K-fel : K-feldspar, Pl. : plagioclase, Va: acidic volcanics, Vi : intermediate to basic volcanics, Ot : other rock fragments, H.M. : heavy minerals, S.M. : secondary minerals, Mtx : matrix.

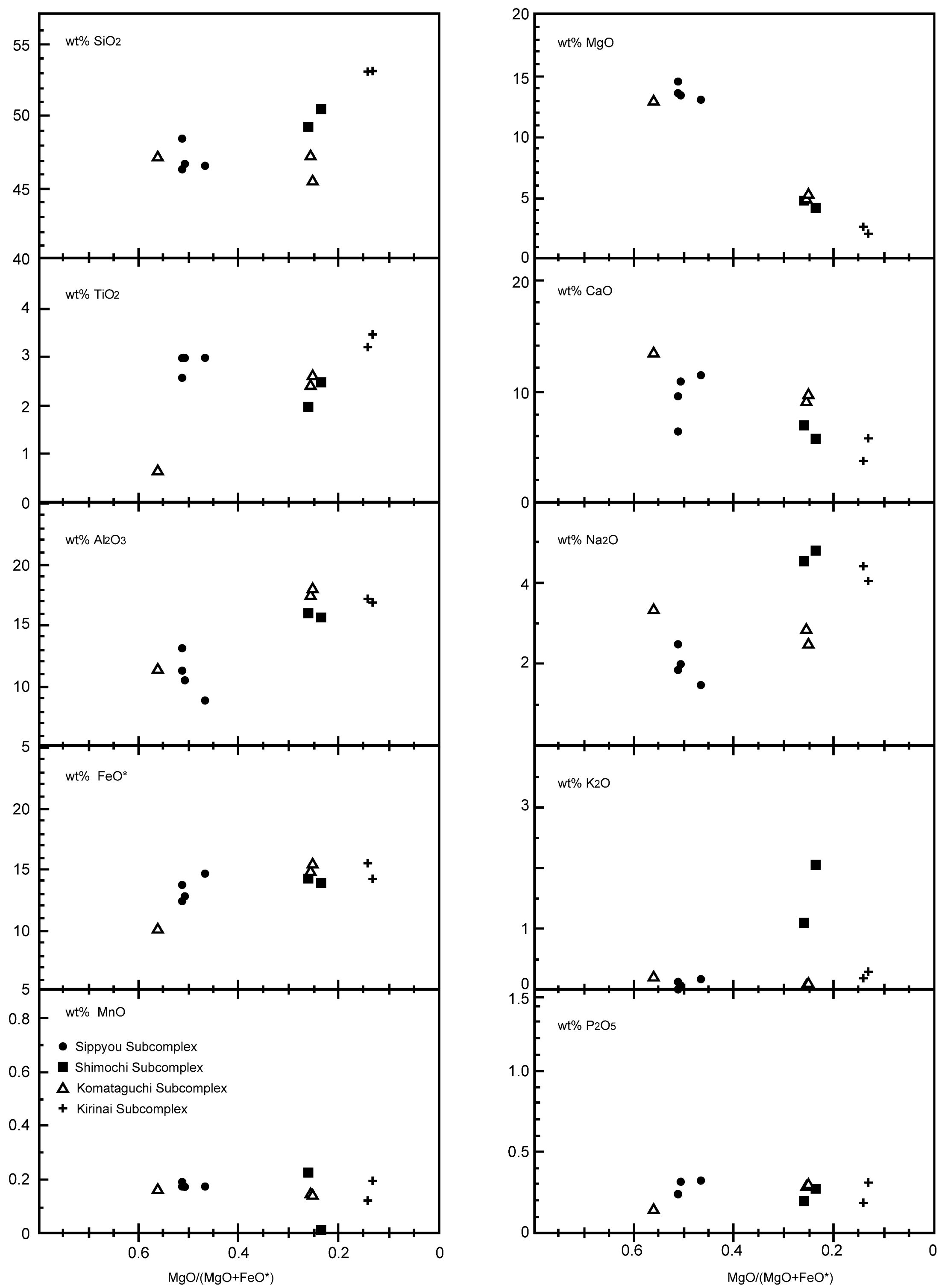


Figure 38. Variation diagrams of major oxides against MgO/(MgO+FeO*) for greenstones in the Kuzumaki-Kamaishi Subbelt. Recalculated to equal 100%.

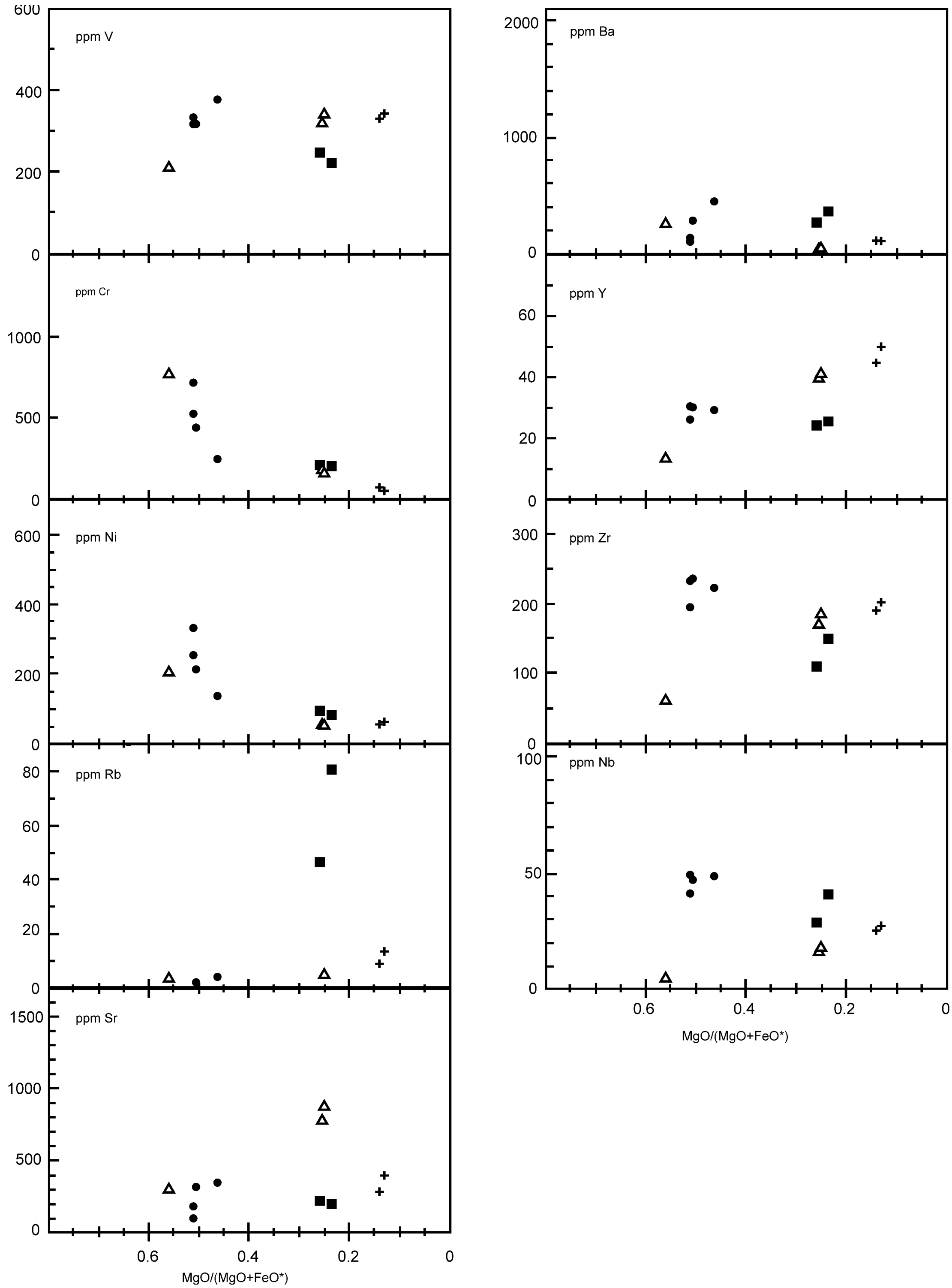


Figure 39. Variation diagrams of trace elements against MgO/(MgO+FeO*) for greenstones in the Kuzumaki-Kamaishi Subbelt. Recalculated to equal 100%.

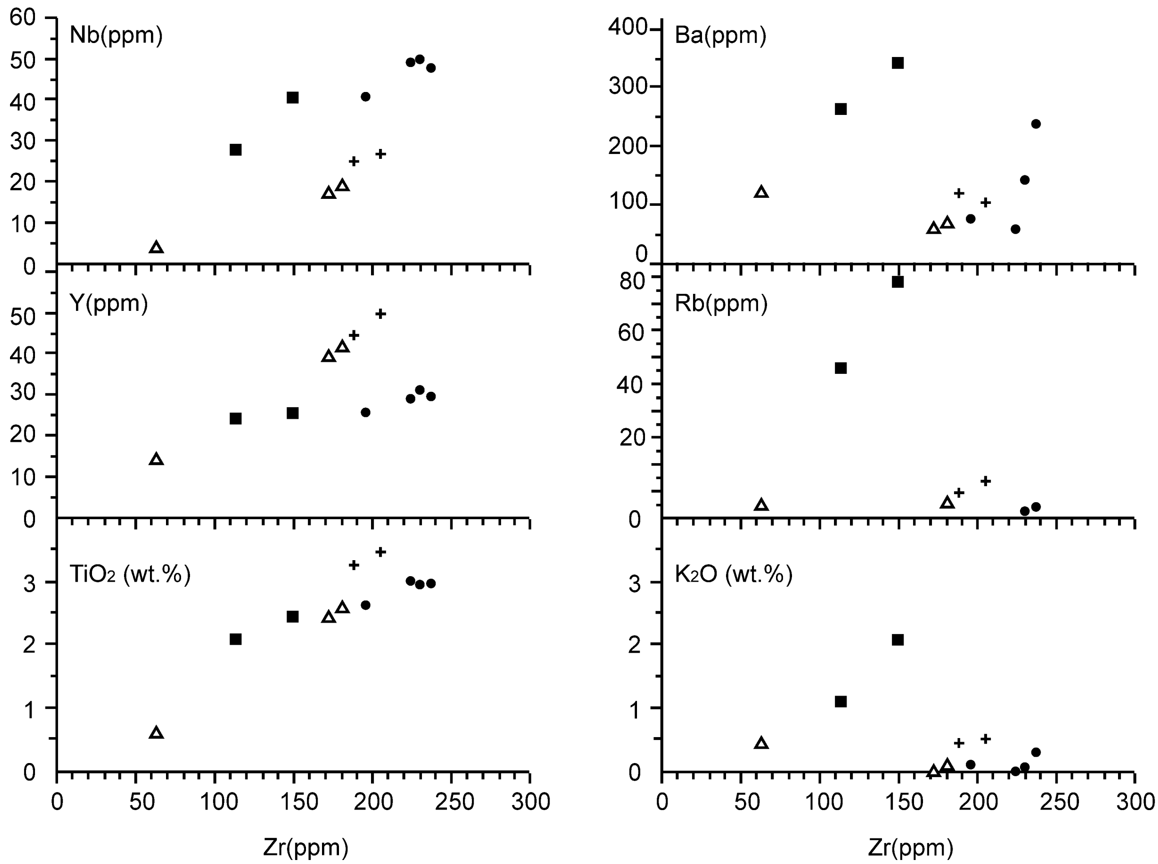


Figure 40. Variation diagram of LIL elements and HFS elements vs. Zr contents of the Kuzumaki-Kamaishi Subbelt. Symbols are given in Figure 38.

and minor acidic volcanics. Fragments of metamorphic and plutonic rocks are not encountered in these thin sections. These results show similarity to sandstones among subcomplexes with abundant quartz, plagioclase, and minor lithic fragments. They plot within the dissected magmatic arc provenance (DMA) of Kumon *et al.* (1992) and overlap part of the Kuzumaki-Kamaishi Subbelt of Okami *et al.* (1992).

6.2. Petrology and geochemistry of greenstones

A representative set of 11 samples was selected for chemical analysis of greenstones from the Shimochi, Sippyou, Komataguchi, and Kirinai Subcomplexes. Limestone-breccia in Minamikawame is associated with angular blocks ranging from several to several tens of centimeters in diameter of hyaloclastite and clinopyroxene-olivine basalts. Hyaloclastite is partly brecciated, and vesicles of hyaloclastite are usually filled with actinolite. The groundmass of the clinopyroxene-olivine basalts is intergranular with up to 20% modal clinopyroxene. Mafic minerals are generally altered by chlorite and sericite. Two samples were used for geochemical analysis : sample Sm-01 was taken from fresh basalt in limestone-breccia in Minamikawame, and sample Sm-02, clinopyroxene-olivine basalt, was collected from the fresh part of a boulder (3 cm in diameter) in the Men'nabezawa Valley.

Isolated blocks of greenstones are patchily distributed in the structural basal part of the Sippyou Subcomplex, which consists of hyaloclastite, hyaloclastite breccia, anophyric basalt, and olivine-augite-basalt. These greenstones are generally associated with slaty cleavages. Four samples (samples K1, K2, K3, and K4) were ophitic basalts collected from fresh parts of basaltic rocks without slaty cleavage. Basaltic rocks in the Komataguchi Subcomplex are exposed in the Kazawa, Ori'awasezawa, Tanetoguchi, and Asse-no-sawa valleys. The Komataguchi Subcomplex is highly sheared, but small parts of the basaltic rocks in the Ori'awasezawa Valley and Kazawa are not sheared. Samples of olivine-augite-plagioclase basalts were collected from the Ori'awasezawa Valley (sample OA-1) and Kazawa (samples KZ-01 and KZ-02). The Kirinai Subcomplex rarely yields greenstones, and majority of the rocks in this subcomplex are difficult to analyze geochemically because of their highly deformed structures. Appropriate samples for geochemical analysis were obtained from pillow basalts (samples YB-01 and YB-02) of the Kirinai Subcomplex, which is out of the study area in the Yoshibesawa Valley.

A suite of 10 major elements and 9 trace elements were analyzed by X-ray fluorescence (XRF ; RIX-2100 ; Rigaku Denki Co.) at the Institute of Mineralogy, Petrology, Economic Geology, Tohoku University, following the procedures of

Table 3. Chemical compositions of the greenstones analyzed by XRF.

Sucomplex	Sippyou Sucomplex				Simochi Sucomplex		Komataguchi Sucomplex			Kirinai Sucomplex	
Sample	K1	K2	K3	K4	Sm-01	Sm-02	KZ-01	KZ-02	OA-01	YB-01	YB-02
%											
SiO_2	45.67	47.40	46.67	46.40	47.07	48.69	44.03	45.67	44.88	52.91	52.92
TiO_2	2.59	2.88	2.97	2.98	2.00	2.37	2.49	2.35	0.55	3.22	3.44
Al_2O_3	11.10	12.72	10.40	8.96	15.58	15.53	17.82	17.41	10.89	17.01	16.83
FeO*	13.42	12.27	12.98	14.80	13.51	13.32	15.00	14.20	9.70	15.16	13.61
MnO	0.18	0.19	0.18	0.18	0.22	0.06	0.14	0.14	0.17	0.12	0.19
MgO	14.39	13.11	13.27	12.88	4.81	4.11	5.01	4.85	12.26	2.47	2.05
CaO	9.32	6.41	10.77	11.38	6.58	5.64	9.31	8.85	12.71	3.50	5.93
Na_2O	1.79	2.45	1.97	1.46	4.35	4.55	2.41	2.67	3.18	4.33	3.52
K_2O	0.21	0.00	0.10	0.33	1.11	2.05	0.21	0.09	0.41	0.39	0.51
P_2O_5	0.24	0.23	0.32	0.34	0.19	0.26	0.28	0.26	0.13	0.19	0.31
Total	98.91	97.66	99.63	99.71	95.42	96.58	96.70	96.49	94.88	99.30	99.31
ppm											
V	316	335	318	373	244	227	344	319	212	327	334
Cr	755	541	428	220	201	195	224	215	787	68	59
Ni	337	217	252	141	90	81	56	55	208	52	58
Rb	n.a.	n.a.	2	4	46	80	5	n.a.	4	9	13
Sr	185	108	308	333	216	200	878	777	301	287	402
Ba	73	59	143	231	262	341	71	61	121	118	101
Y	26.0	31.1	29.8	29.0	24.3	25.5	41.7	39.0	13.9	44.6	49.9
Zr	196	230	238	224	113	149	181	172	62	188	205
Nb	41	50	48	49	28	41	19	17	4	25	27

FeO* : total Fe as FeOs ; n.a. : not analysed.
Samples K1-K4 : olivine-augite basalt (39°30′39″N, 141°51′32″E, Kogawa Valley). Sample Sm-01 : clinopyroxene-olivine basalt (39°33′38″N, 141°49′7E, west of Minamikawame). Sample Sm-02 : clinopyroxene-olivine basalt (39°32′14″N, 141°50′34″E, the mouth of the Men'nabezawa Valley). Samples KZ-01 and KZ-02 : olivine-clinopyroxene-plagioclase basalt (39°28′42″N, 141°44′51″E, west of Nakayama along the Kazawa Valley). Sample OA-01 : ophitic basalt (39°28′14″N, 141°47′27″E, north of Komataguchi in the lower part of the Oriawase Valley). Samples YB-01 and YB-02 : pillow basalt (39°35′12″N, 141°31′50″E, Yoshibesawa Valley).

Kimura and Yamada (1996). These selected samples were cut and cleaned, and then chips with veins such as quartz and calcite were removed from the crushed samples, under a binocular microscope. These samples were then powdered and dried. Using mixed alkali flux, lithium tetraborate ($Li_2B_4O_7$) and lithium metaborite ($LiBiO_2$), and fusion conditions at a temperature of 1050°C for 7 min, flux-to-sample ratio 1 : 1 glass beads were prepared. Table 3 shows the full analytical results.

Figure 38 presents the variation diagrams of major oxides against MgO/(MgO+FeO*) for the selected greenstones after recalculation to sum to 100%. These samples have low SiO_2 (46-54% by weight), rich alkali elements, and relatively large high-field strength (HFS) elements (TiO_2 : 3 wt %, Nb : 20-50 ppm). Although very few samples were examined in this study, greenstones of the Shimochi Subcomplex are rich in Na_2O and K_2O, and samples from the Sippyou Subcomplex are rich in MgO/(MgO+FeO*). Variation diagrams of trace elements against MgO/(MgO+FeO*) are shown in Figure 39. The subcomplexes show slightly different patterns of HFS and immobile incompatible trace elements. Greenstones in the Shimochi and Sippyou Subcomplexes have high Nb and low Y. With the exception of sample OA-01, those in the Kirinai and Komataguchi Subcomplexes have low Nb and high Y. The large-ion lithophile (LIL) elements, relatively mobile incompatible elements with alternation, also show a different pattern in the subcomplexes. All the samples except for those from the Shimochi Subcomplex have low Rb, and all the samples have very low Ba. Greenstones from the Komataguchi Subcomplex, with the exception of sample OA-01, are high in Sr, and those from the Shimochi, Sippyou, and Kirinai Subcomplexes are low in Sr.

In the evaluation of alternation, Figure 40 illustrates the relationships between incompatible elements and Zr content. These diagrams could show positive relationships if the original contents for these trace elements are preserved (Pearce and Cann, 1973 ; Winchester and Floyd, 1976) because Zr shows high incompatibly to olivine, augite, and plagioclase, which are common minerals in basaltic rocks (Fujimaki *et al.*, 1984 ; Lemarchand *et al.*, 1987). The examined rocks have mainly positive Nb, Y, and TiO_2 values and show no trends in Ba, Rb, and K_2O. Discrimination based on HFS elements such as Nb, Y, Ti, and Zr can be made by plotting the discrimination diagrams proposed by Pearce (1982 ; Fig. 41a), Peace and Norry (1979 ; Fig. 41b), Meschede (1986 ; Fig. 41c), and Tatsumi *et al.* (1998 ; Fig. 41d).

The greenstones in the Shimochi and Sippyou Subcomplexes have enriched Ti/Y and Nb/Y values, plotting in the within-plate basalt (WPB) in Figure 41a. The greenstones in the Komataguchi and Kirinai Subcomplexes, with the exception of sample OA-01, also plot in the WPB near the normal mid-ocean ridge basalt (MORB) in Figure 41b. The Zr/Y

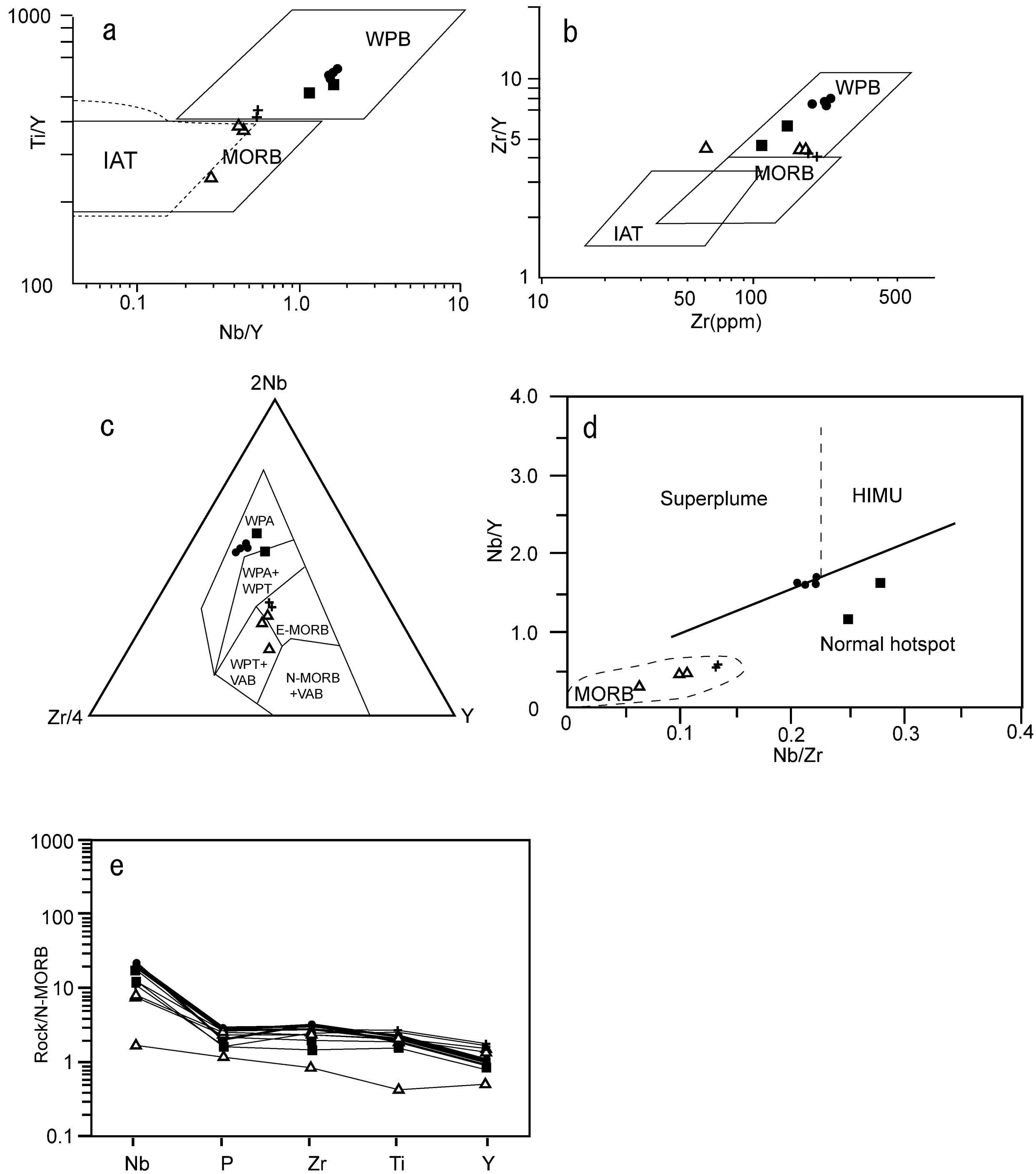


Figure 41. Discrimination diagram for greenstones of variable tectonic settings and for greenstones of the Kuzumaki-Kamaishi Subbelt. (a) Pearce (1982); (b) Pearce and Norry (1979). MORB: mid-ocean ridge basalt, IAT: island-arc tholeiite, WPB: within-plate basalt. (c) Meschede (1986). N-MORB: N-type mid-oceanic ridge basalt, E-MORB: enriched-type mid-oceanic ridge basalt, WPT: within-plate tholeiite, WPA: within-plate alkali basalt, VAB: volcanic arc basalt. (d) Tatsumi *et al.* (1998). HIMU: High - μ ($\mu = {}^{238}U/{}^{204}Pb$) basalt, MORB: mid-ocean ridge basalt, (e) N-MORB: normalized trace element spider diagrams, N-MORB-normalized values are after Sun and McDonough (1989). Symbols are given in Figure 38.

ratio of the greenstones from the Komataguchi and Kirinai Subcomplexes is approximately 4. In the discrimination by Meschede (1986), the greenstones in the Shimochi and Sippyou Subcomplexes plotted in within-plate alkali basalt (WPB), but those in the Komataguchi and Kirinai Subcomplexes, with the exception of sample OA-1, plotted in enriched-MORB (E-MORB) + volcanic arc basalt (VAB) and within-plate tholeiite (WPT) + VAB. Based on these geochemical discrimination diagrams, greenstones in the Shimochi and Sippyou Subcomplexes are associated with WPBs. However, the origin of greenstones in the Kirinai and Komataguchi Subcomplexes is difficult to determine because they plot to different discrimination areas.

We examined the immobile HFS element character (Nb, P, Zr, Ti, Y) of the greenstones in this study using an N-MORB-normalized spider diagram (Sun and McDonough, 1989). In this diagram (Fig. 41e), elements of all the samples, except for sample OA-01, increase to the left. It is noteworthy that P is relatively depleted, and consequently these patterns are very similar to those in oceanic island tholeiite (OIT).

The origin of within-plate basalts of the Shimochi and Sippyou Subcomplexes was determined by the geochemical discrimination diagrams of Tatsumi *et al.* (1998). This diagram is useful for discriminating superplume, HIMU basalts (high $\mu = {}^{238}U/{}^{204}Pb$), and normal hotspots by Nb/Zr-Nb/Y ratios. The greenstones from the Shimochi and Sippyou Subcomplexes range from 0.2 to 0.3 in Nb/Zr and from 0.5 to 1.5 in Nb/Y, thus plotting as normal hotspots. These geochemical data suggest that greenstones in the Shimochi and Sippyou Subcomplexes are WPBs, hotspot-type in origin. More precise geochemical analysis is required for greenstones in the Kirinai and Komataguchi Subcomplexes.

7. Discussion

7.1. Origin of rocks

7.1.1. Carbonate rocks and greenstones

Limestones in the Kuzumaki-Kamaishi Subbelt rarely preserve fossils because of thermal metamorphism, but Middle Permian fusulinids including *Pseudodoliolina* cf. *ozawai* Yabe et Hanzawa and *Neoschwagerina margaritae* Deprat (Tazawa *et al.*, 1997); Mesozoic scleractinian corals (Ehiro *et al.*, 2001) and Early Permian fusulinids including *Nipponitella* sp. and *Chalaroschwagerina vulgaris* (Schwellwien) (Onuki and Kudo, 1954; Yoshida and Katada, 1964) have been reported from the upper Komatsugura Subcomplex of the Tanesashi Complex, the Shimochi Subcomplex of the Tsugaruishi Complex, and the Kotanichi Subcomplex of the Karomori Complex, respectively. Contemporaneous limestone blocks are limitedly found from the same subcomplex in this area, suggesting that these limestone blocks in each subcomplex have been supplied from the same source in the same age as proposed by Ehiro *et al.* (2001).

The patterns of occurrence suggest that the supply systems of the limestones differ among the upper Komatsugura, Shimochi, and Kotanichi Subcomplexes. Limestones yielding Middle Permian fusulinids in the upper Komatsugura Subcomplex were supplied as granular-pebbly blocks and a few large blocks in the hemipelagic mudstone matrix, associated with basaltic pebbles. These blocks are concentrated in mudstone without shear structures and thus are debris flow in origin. Tazawa *et al.* (1997) indicated that the faunal compositions of fusulinoidean fossils of the upper Komatsugura Subcomplex in Fukushi are similar to those of the seamount-reef complex in the Akiyoshi, Mino, and Sambosan belts; therefore, the limestones and basaltic rocks are considered to have originated from the seamount-reef complex.

Limestone breccia of the Shimochi Subcomplex is marked by presence of limestone, blocks of ribbon chert, unconsolidated angular pebbles of radiolarian-bearing siliceous mudstone, and pebbles of Hawaiian-type hotspot basalts. The matrix is composed of carbonate grains, isolated radiolarians coated with siliceous mudstone, and lithic fragments corresponding to the associated blocks, suggesting that the depositional site was located outward from the trench. This breccia is also characterized by upward-fining sediments with laminations; the sediments are composed of pebbly to sandstone grains and range in thickness from 30-50 m. Blocks of ribbon chert yield Early to Middle Triassic conodonts and radiolarians. Although the depositional age of siliceous mudstone is unknown, isolated radiolarians are coated with siliceous mudstone indicating that these mudstones were unconsolidated at the time of limestone-breccia supply; consequently, the limestone breccia was deposited on the provenance of siliceous mudstone from topographic highs of oceanic islands at that time. Blocks of ribbon chert were presumably derived from an area landward of the trench because the ribbon chert shows intrafolial folds in each block.

Limestones in the Kotanichi Subcomplex formed in two steps: first, the limestone breccia was formed, and then blocks of limestone breccia collapsed. Okami (1990) and Okami *et al.* (1993) noted that the upper and basal boundaries of the Early Permian limestones are usually in fault contact with Triassic ribbon chert. This suggests that the limestones and ribbon cherts are exotic blocks in origin. Limestones are composed of limestone breccia in association with basaltic pebbles, and were thus supplied from topographic highs of basalts. After this limestone was completely consolidated, limestone blocks were mixed with chert blocks by tectonic or sedimentary mechanisms.

Tsuchiya *et al.* (1999) examined minor elements such as HFS elements to determine the origin of greenstones in the North Kitakami Belt. Based on these studies, the chemical and mineralogical characteristics of greenstones in the Kuzumaki-Kamaishi and Akka-Tanohata subbelts represent seamount fragments formed in a Hawaiian-type hotspot by WPT (ocean island tholeiitic) magmatism or from ocean islands by within-plate alkali basaltic magmatism. The N-MORB-type basalt has only been reported from Gando in the Kuzumaki-Kamaishi Subbelt (Tsuchiya *et al.*, 1999). Basaltic rocks in the Shimochi and Sippyou Subcomplexes also originated from a Hawaiian-type hotspot by WPT magmatism. However, the original geologic settings of basaltic rocks in the Sippyou Subcomplex can only be determined as Hawaiian-type seamounts, because of the isolated occurrences of blocks in the subcomplex. Thus, the Kuzumaki-Kamaishi Subbelt usually yields basaltic rocks from seamounts.

7.1.2. Pelagic sequences

Our study and additional information from previous studies (Ehiro *et al.*, 2001 ; Nakae and Kamata, 2003 ; Okami, 1990 ; Okami and Ehiro, 1988 ; Okami *et al.*, 1993 ; Suzuki and Ogane, 2004 ; Yoshihara *et al.*, 2002) indicate that pelagic sequences of chert and siliceous mudstone date as Early Permian to Middle Jurassic in the Kuzumaki-Kamaishi Subbelt. Siliceous mudstone of a similar age was accreted along the eastern margin of the Asian continent in the Jurassic and Cretaceous (Wakita and Metcalfe, 2005) ; this accretionary complex was probably formed as a single chain and is now separated as the Badzhal, Vikin, Nadanhada, Bikin, Samarka, Ashio-Mino-Tamba, Taukha, Oshima, North Kitakami, Southern Chichibu, (?) Northern Chichibu, and Busuanga belts (Suzuki *et al.*, 2005 ; Yamakita and Otoh, 2000a ; Zhamoras and Matsuoka, 2004). These belts were duplicated by left-lateral strike-slip displacement in the Cretaceous and were then blocked and separated from the Asia continent by the opening of the Japan Sea in the Cenozoic. Although tectonic reconstructions of the Jurassic accretionary complex in Japan are still being discussed among researchers, the original length of this accretionary complex reaches up to several thousand kilometers from the Badzhal Belt, the northernmost remnant, to the Busuanga belt, the southernmost remnant (e.g., Yamakita and Otoh, 2000b). The southernmost part of the original accretionary complex was positioned around 15°N (e.g., Wakita and Metcalfe, 2005 ; Yao, 2000). Consequently the northernmost part of the Jurassic accretionary complex could be around 50°N, at most, if the complex is aligned along a meridian line. Wakita and Metcalfe (2005) illustrated a northwest direction for the accreted trench and accretion of the Jurassic accretionary complex between 15°N and 25°N. Radiolarian faunas preserving the original species compositions have been reported from Aalenian manganese nodules from the Mino Belt (Takemura, 1986 ; Yao, 1997), the Sippyou Subcomplex of the Kuzumaki-Kamaishi Subbelt (Suzuki and Ogane, 2004), and the Northern Chichibu Belt (Hori and Wakita, 2006). These species are considered to represent equatorial faunas in the Mino Belt, equatorial to lower latitudinal faunas in low-productivity areas in the Kuzumaki-Kamaishi Subbelt, and colder faunas in the Northern Chichibu Belt. The Kuzumaki-Kamaishi Subbelt was initially positioned south of the Mino Belt (Yamakita and Otoh, 2000a, 2000b). In contrast to this presumed original relationship of the Northern Chichibu and Mino belts, Hori and Wakita (2006) proposed that fauna from the Northern Chichibu Belt were high-latitudinal fauna based on the presence of cold radiolarian groups such as the genus *Parvicingula*. This inconsistency can be easily solved by the following interpretation of productivity rathern than mixed interpretation with provincialism. High-productivity regions, such as areas of upwelling, occur along the equatorial to lower-middle latitudinal western margin of the Pacific near the Kuroshio Current, where productivity is typically greater at relatively higher latitudes than in the equatorial zone (e.g., Yoder and Kennelly, 2003). If this system was present in the Jurassic, the depositional site of the siliceous mudstone and mudstone of the Kuzumaki-Kamaishi Subbelt was a low productivity area, whereas the depositional site of the Northern Chichibu Belt was in lower productivity region a lower latitudinal region.

7.1.3. Clastic rocks

The provenance of siliciclastic rocks in the Kuzumaki-Kamaishi Subbelt is presumed to be an island arc, whereas that of siliciclastic rocks in the Akka-Tanohata Subbelt is considered to be continental regions (Okami and Ehiro, 1988 ; Okami *et al.*, 1992). In agreement with previous studies, the sandstones in this study plotted to the dissected magmatic arc (DMA) in the discrimination diagram proposed by Kumon *et al.* (1992, 2000). In addition, sand grains of the Oshima Belt, a direct northern extension of the eastern part of the Kuzumaki-Kamaishi Subbelt and western part of the Akka-Tanohata Subbelt, were derived from Precambrian rocks which were metamorphosed to granulite facies, as shown by the detrital garnet and SHRIMP U/Pb ages of detrital zircon grains (Kawamura *et al.*, 2000). Kawamura *et al.* (2000) also pointed out that recycled grains could be supplied from volcanic arcs in the Oshima Belt. The eastern portion of the Oshima Belt is lithologically correlated to the Akka-Tanohata Subbelt, suggesting that the “continental regions” of Okami and Ehiro (1988) are identical to the Precambrian rocks of Kawamura *et al.* (2000). The DMA in our study could correspond with the “volcanic arcs” of Kawamura *et al.* (2000).

The Kariya Subcomplex is marked by the presence of intraformational conglomerates with rounded chert, sandstone, granite, and rhyolite, suggesting that these conglomerates were supplied as slope basin deposits from the continental slope. There are no pebbles of metamorphic rocks, and consequently the Precambrian rocks discussed above were not exposed near the depositional site of the Kariya Subcomplex. The presence of rounded chert, siliceous mudstone, and sandstone strongly suggests the exposed outcropping of accretionary complexes near the distribution areas of granite and rhyolite. This provenance is, however, an atypical source of clastic rocks because conglomerate is a minor lithology in the Kariya Subcomplex.

The intraformational conglomerate of the Furuyadomori Subcomplex is well-sorted chert breccia, suggesting that these chert fragments tansported relatively short distances but were long enough for sorting to occur. Lithic fragments of chert are common not only in the conglomerate of the Furuyadomori Subcomplex, but also in sandstones of the Kuzumaki-Kamaishi Subbelt in the study area, suggesting that the origin of chert was usually exposed in the provenance of clastic rocks.

A typical chert-clastics sequence is associated with the sandstone that overlies hemipelagic siliceous mudstone and mudstone (e.g., Matsuda and Isozaki, 1991 ; Matsuoka, 1992), but the chert-clastics sequences of the Nagaiwamori and Sippyou Subcomplexes are only associated with mudstone. This mudstone occasionally contains abundant radiolarians, which indicates hemipelagic sediments. These subcomplexes are very rarely associated with siliciclastic sandstone, and thus clastic sediments began to reach the exposure of the hemipelagic mudstone of the Nagaiwamori and Sippyou Subcomplexes.

7.2. Age-lithology profiles in the North Kitakami Belt (Fig. 42)

The Kuzumaki-Kamaishi Subbelt and Akka-Tanohata Subbelt have similar tectonostratigraphic sequences but of different ages (Okami and Ehiro, 1988). According to Okami and Ehiro (1988), with the exception of the Mikaeribashi Limestone Conglomerate, Paleozoic cherts and limestones are exclusively present in the Kuzumaki-Kamaishi Subbelt, whereas most the Mesozoic limestones are exclusively present in the Akka-Tanohata Subbelt. Yoshihara *et al.* (2002) presumed a younging accretion age of the trench eastward from the Kuzumaki-Kamaishi Subbelt to the Akka-Tanohata Subbelt, but Nakae and Kamata (2003) pointed out that this younging trend is not as simple as stated by Yoshihara *et al.* (2002). Several important fossil data reports have been published since Okami and Ehiro (1988) recognized the differences in ages, and we have used these data and our new data to create a revised age-lithostratigraphic profile.

Carboniferous fusulinid fossils including *Rugosofusulina* cf. *serrata* Rauser-Chernousova, the oldest fossils in the Kuzumaki-Kamaishi Subbelt, are found in limestones in the Sakamotosawa and Sekiguchigawa valleys (Onuki, 1969; Sugimoto, 1972), although the assigned ages of these fossils must be confirmed by reexamination of the original specimens or re-sampling because of the absence of illustrations. All the Permian limestones are found in the Kuzumaki-Kamaishi Subbelt (Choi, 1972; Moriai and Oikawa, 1969; Murai *et al.*, 1985; Okami and Murata, 1974a, 1974b; Onuki, 1956, 1969; Onuki and Kudo, 1954; Sugimoto, 1972; Tamura *et al.*, 1952; Tazawa *et al.*, 1997; Yoshida and Katada, 1964). Permian ribbon chert is exclusively recognized in the Kuzumaki-Kamaishi Subbelt by occurrences of conodonts (Murai *et al.*, 1981; Okami *et al.*, 1993; Toyohara *et al.*, 1980; Yoshida and Katada, 1984) and radiolarians (Kametaka *et al.*, 2005). In accordance with Okami and Ehiro (1988), Paleozoic limestones and cherts are exclusively present in the Kuzumaki-Kamaishi Subbelt, with the exception of the Mikaeribashi Limestone conglomerate in the Akka-Tanohata Subbelt.

The Triassic facies have been recognized as chert and siliceous mudstone in the Kuzumaki-Kamaishi Subbelt, but as chert, siliceous mudstone, and limestone in the Akka-Tanohata Subbelt. In the Kuzumaki-Kamaishi Subbelt, Late Olenekian radiolarians and conodonts have been obtained from siliceous mudstone and chert (Ehiro *et al.*, 2001; Murai *et al.*, 1981; Toyohara *et al.*, 1980), and conodonts ranging from Anisian to Norian in age have been recovered from chert (Ehiro *et al.*, 2001; Murata and Nagai, 1972; Okami, 1990; Okami *et al.*, 1993; Toyohara *et al.*, 1980; Yoshida, 1980). Rhaetian conodonts have not been found in the Kuzumaki-Kamaishi Subbelt, probably because of the small diversity and few Rhaetian conodont elements. In the Akka-Tanohata Subbelt, Late Olenekian conodonts are found in siliceous mudstone and chert (Toyohara *et al.*, 1980), with Anisian-Norian conodonts and Norian radiolarians including *Paracanoptum nova* (Yao) (equivalent to *Triassocampe nova* in the original papers) recovered from chert (Oho and Iwamatsu, 1986; Toyohara *et al.*, 1980). The large limestone body of the Akka "Formation" (=Subcomplex in our paper), which overlies greenstones of the Sawayamagawa "Formation" and the underlying chert, contains scleractinian corals, stromatoporoid fossils, and crinoids (Hanzawa, 1954; Hase *et al.*, 1956; Shimazu *et al.*, 1970). It is dated as Late Triassic by occurrences of Carnian-Norian conodonts (Murai *et al.*, 1985; Murata and Sugimoto, 1971; Toyohara *et al.*, 1980).

Jurassic to Early Cretaceous fossils were found from siliceous mudstone and mudstone in both subbelts after Okami and Ehiro (1988) published their article. Aalenian (early Middle Jurassic) radiolarian faunas were obtained from a manganese nodule in mudstone of the Sippyou Subcomplex (Suzuki and Ogane, 2004; Yoshihara *et al.*, 2002) and from that of the Kotanichi Subcomplex (this study). Early Jurassic radiolarians have been found from chert east of Morioka in the Kuzumaki-Kamaishi Subbelt (Matsuoka, 1988) and Late Jurassic radiolarians were found in mudstone of the Seki "Formation" from the east marginal part of the Kuzumaki-Kamaishi Subbelt (Nakae and Kamata, 2003). Middle Jurassic radiolarians were found in siliceous mudstone and chert from the eastern margin (Omoto area) of the Akka-Tanohata Subbelt (Matsuoka, 1987; Matsuoka and Oji, 1990), and Late Jurassic to earliest Cretaceous radiolarians were recovered from mudstone in Omoto area (Matsuoka, 1987; Minoura and Tsushima, 1984). Radiolarians have been recognized in chert and siliceous mudstone of both subbelts in thin sections (e.g., Ehiro *et al.*, 2001; Nakamura, 1911; Suzuki and Ogane, 2004), but these fossils are difficult to extract from rocks due to dissolution. The presence of the Middle-Late Jurassic radiolarians in siliceous mudstone and mudstone suggests that part of the underlying chert is presumably Jurassic in age. The Kuzumaki-Kamaishi Subbelt contains small blocks of the Mesozoic coral-bearing limestone in Mount Ippaimori (Murai *et al.*, 1986) and in the Shimochi Subcomplex (Ehiro *et al.*, 2001). The limestone of the Shimochi Subcomplex may be older than Middle Jurassic, as discussed above.

An age diagnostic ammonoid fossil of sandstone in the North Kitakami Belt has only been reported from the probable Takayashiki "Formation" of the Akka-Tanohata Subbelt (Onuki, 1956). This specimen is recently identified as *Perisphinctes* (*Kranaosphinctes*) sp. (Tadashi Sato, personal communication, 2006) in the current taxonomic scheme, dating as Oxfordian (Fig. 43). Onuki (1956) stated that this specimen was collected by T. Mitome near the Iwaizumi electric power plant and was donated through K. Hase to Tohoku University. The fossil locality is formally recorded in the paper, but Hase (personal communication, 2004) said that the specimen was collected from a float on the river bed near the mouth of a southern tributary of the Omotogawa River, which splits from the main channel east of Soirigawa. The host rock is very coarse-grained feldspathic sandstone with rip-up clasts of mudstone, the lithology of which closely

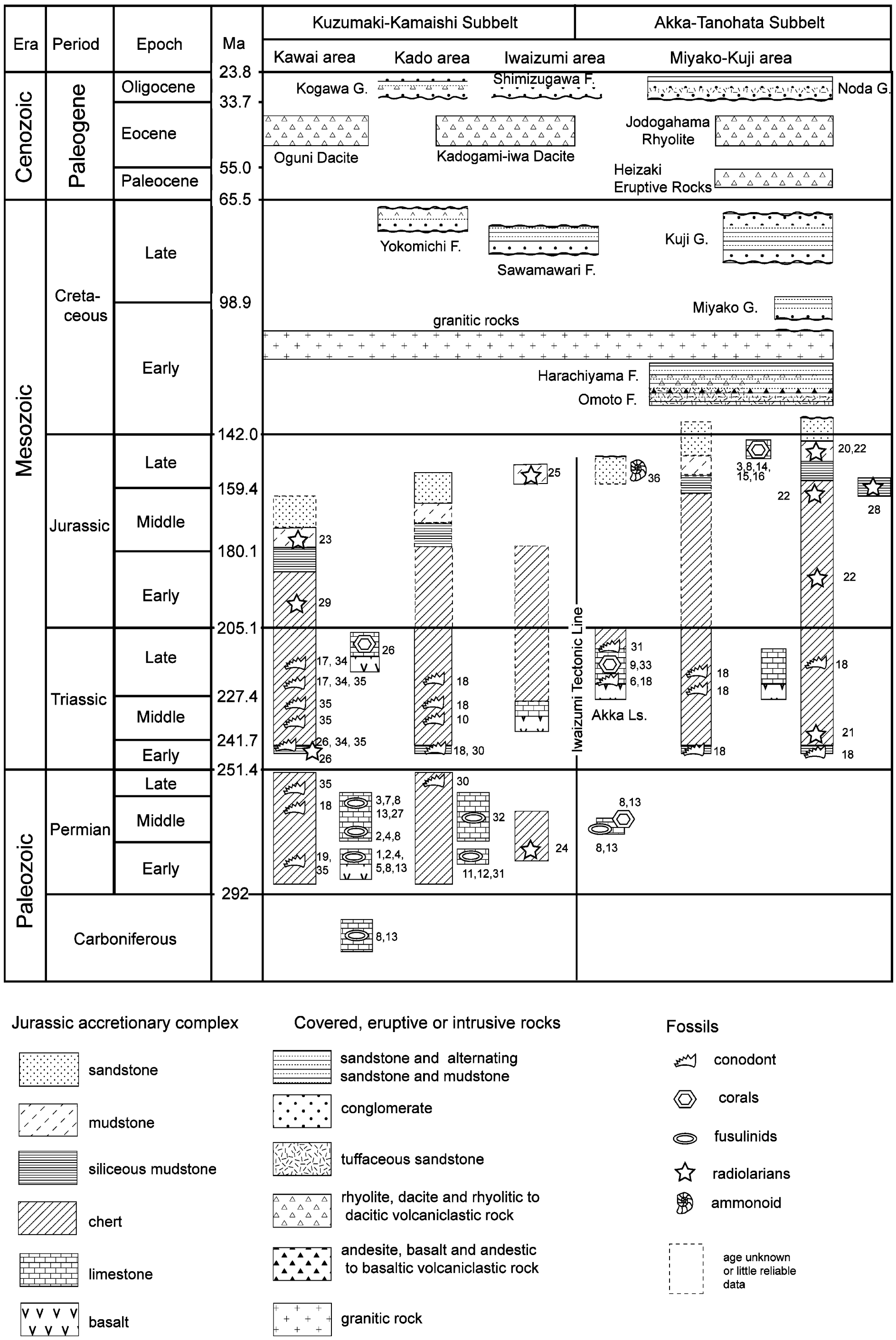


Figure 42. Schematic age and lithostratigraphic diagram of the Northern Kitakami Massif. Abbreviation numbers indicate the data source for the age. 1. Tamura *et al.* (1952), 2. Onuki and Kudo (1954), 3. Onuki (1956), 4. Yoshida and Katada (1964), 5. Moriya and Oikawa (1969), 6. Murata and Sugimoto (1971), 7. Choi (1972), 8. Sugimoto (1972), 9. Shimazu *et al.* (1970), 10. Murata and Nagai (1972), 11. Okami and Murata (1974a), 12. Okami and Murata (1974b), 13. Onuki (1969), 14. Onuki (1959), 15. Murata (1962), 16. Tsushima and Takizawa (1977), 17. Yoshida (1980), 18. Toyohara *et al.* (1980), 19. Yoshida and Katada (1984), 20. Minoura and Tsushima (1984), 21. Oho and Iwamatsu (1986), 22. Matsuoka (1987), 23. Suzuki and Ogane (2004), 24. Kametaka *et al.* (2005), 25. Nakae and Kamata (2003), 26. Ehiro *et al.* (2001), 27. Tazawa *et al.* (1997), 28. Matsuoka and Oji (1990), 29. Matsuoka (1988), 30. Murai *et al.* (1981), 31. Murai *et al.* (1985), 32. Murai *et al.* (1986), 33. Hanzawa (1954), 34. Okami (1990), 35. Okami *et al.* (1993), 36. this paper.

Figure 43. *Perisphinctes* (*Kranaosphinctes*) sp. (ammonoid) from very coarse-grained feldspathic sandstone, probably of the Takayashiki "Formation" of the Akka-Tanohata Subbelt, reported by Onuki (1956) as *Perisphinctes* (?) sp. The registered number of the specimen is IGPS coll. cat. No. 86378, the Tohoku University. One square equates 1 cm length.

resembles that of the sandstone of the Takayashiki "Formation" near the fossil locality. Therefore, the specimen is considered to have derived from the Takayashiki "Formation". Otherwise, no age-diagnostic fossils are known from the sandstone, which probably dates to the Middle to Late Jurassic or younger in the Kuzumaki-Kamaishi Subbelt, based on the ages of the siliceous mudstone and mudstone.

In summary, the Kuzumaki-Kamaishi Subbelt is comprised of Carboniferous to Upper Permian fusulinid-bearing limestones, Lower Permian to probable Jurassic chert, upper Olenekian siliceous mudstone, Middle to Late Jurassic siliceous mudstone and mudstone, greenstone of unknown age, siliciclastic rocks of probable Middle-Late Jurassic age, and a minor amount of Jurassic or older coral-bearing limestones. The Akka-Tanohata Subbelt is composed of upper Olenekian siliceous mudstone, upper Olenekian to probable Jurassic chert, Middle Jurassic to lowest Cretaceous mudstone and siliceous mudstone, Triassic macrofossil-bearing limestone overlying within-plate basalts, Jurassic (?) limestone, and siliciclastic rocks of probable Middle Jurassic to earliest Cretaceous age. The compilation reveals that the geologic structure of the North Kitakami Belt appears to be more complex than predicted by Yoshihara *et al.* (2002).

7.3. Tectonostratigraphic correlations

The geological framework of the Kitakami Massif is considered to be similar to that of Southwest Japan (e.g., Otsuki and Ehiro, 1992). According to Otsuki and Ehiro (1992), the South Kitakami Belt correlates with the Kurosegawa Belt based on the presence of Silurian to Devonian shallow marine deposits, Silurian acidic tuff, the similarity of faunas and floras, the age and petrography of plutonic rocks, and the types of metamorphic rocks. The serpentine melange of the Kurosegawa Belt is considered to be an arc remnant (Maruyama, 1981); these characteristics are similar to those of the Miyamori ultrabasic rocks of the South Kitakami Belt (Ozawa, 1984, 1988). The outer side of the Kurosegawa Belt is occupied by a Jurassic accretionary complex, the Southern Chichibu Belt, in Southwest Japan. The Akka-Tanohata Subbelt of the North Kitakami Belt is marked by basaltic lavas (the Sawayamagawa "Formation") and overlying limestone (the Akka "Formation") and is correlated with the Sambosan Unit of the Southern Chichibu Belt (Shimazu *et al.*, 1970; Yoshida, 1975). This correlation suggests that the Kuzumaki-Kamaishi Subbelt correlates to the Southern Chichibu Belt north of the Sambosan Unit. The Southern Chichibu Belt is subdivided into the Ohirayama, Togano, and Sambosan units (Matsuoka *et al.*, 1998), of which the Ohirayama and Togano units are candidates for the units that correlate to the Kuzumaki-Kamaishi Subbelt. Although the Ohirayama Unit is characterized by mixed rock, whereas the Togano Unit is characterized by repetition of a chert-clastics sequence, this structure could change within the same tectonostratigraphic unit due to regional differences in deformation; thus, differences in structure are less important for correlation in this case. In addition, the width of the Kuzumaki-Kamaishi Subbelt reaches up to 150 km, 15 times wider than the Southern Chichibu Belt. The exact correlative tectonostratigraphic units to the Kuzumaki-Kamaishi Subbelt have not yet been detected in the Southern Chichibu Belt, but the Kuzumaki-Kamaishi Subbelt might include part of a missing unit in the Southern Chichibu Belt.

8. Concluding remarks

Mapping part of the Kuzumaki-Kamaishi Subbelt of the North Kitakami Belt has revealed the geologic structure of the study area (Fig. 44). The results compiled in this study reconstruct the following tectonic history of the Kuzumaki-Kamaishi Subbelt.

After the oceanic plate formed at an uncertain age as a depositional site of pelagic sequences and associated rocks of the Kuzumaki-Kamaishi Subbelt, fusulinid-bearing limestones as a source of limestone-breccias in the Tanesashi and Kotanichi Subcomplexes were built up in the Carboniferous (?) and Permian on the topographic highs of hotspot-type basalts. They flowed onto an unknown basement as contemporaneous deposits or in a subsequent age. Based on data from the Northern Kitakami Massif, ribbon cherts accumulated on the ocean floor in pelagic environments from the Early Permian to Middle/Late Jurassic. However, Late Carboniferous conodont fossils were recovered from

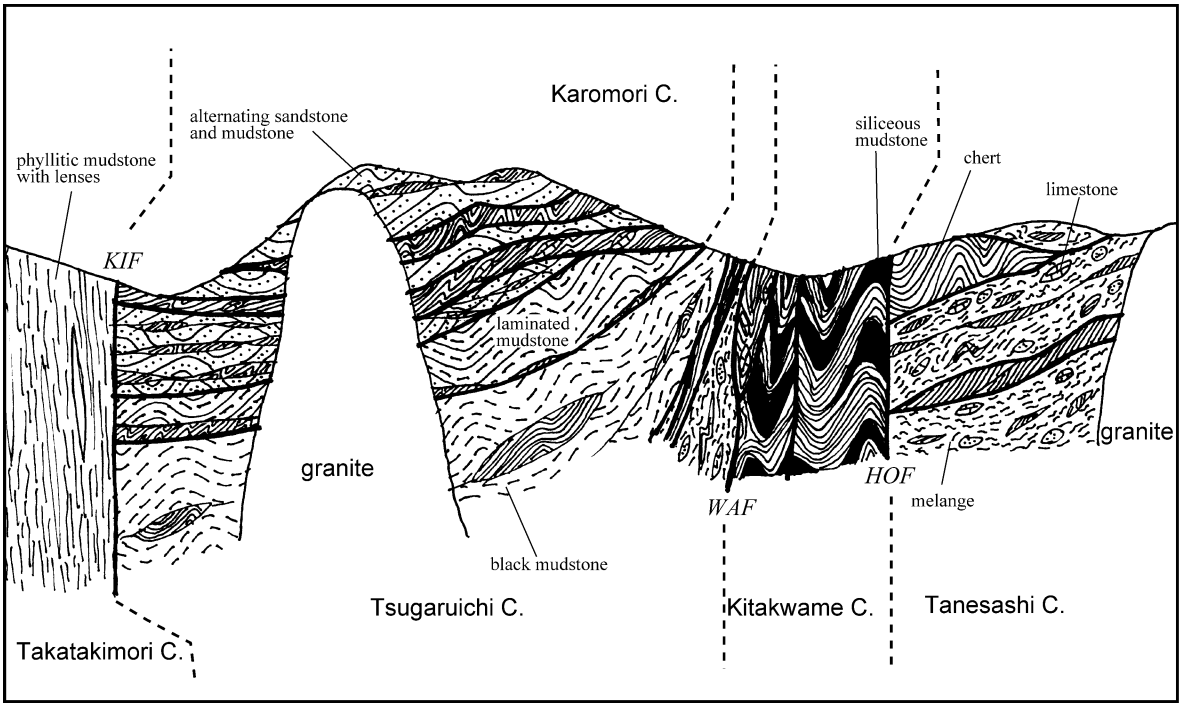


Figure 44. Schematic structure of the Kuzumaki-Kamaishi Subbelt in the studied area.

chert distributed in the Kodomari area at the northwestern extension of the Kuzumaki-Kamaishi Subbelt. Thus the oceanic plate of the Kuzumaki-Kamaishi Subbelt already existed at or before the Late Carboniferous. Later than the deposition of ribbon chert, siliceous mudstone gradually covered the ribbon chert in the Middle to Late Jurassic at a site where siliciclastic mud and silts could be transported from the continental area. The original geographic relationships between the fusulinid-bearing limestones and the ribbon cherts are unknown. Although the precise age is unknown, scleractinian-coral-bearing limestones formed before the Middle Jurassic on a topographic high of hotspot-type basalts of unknown age. This limestone collapsed and flowed, in association with basalt fragments, into the depositional site of radiolarian-bearing siliceous mudstone probably in the Middle Jurassic, as a source of the limestone breccia of the Shimochi Subcomplex, and blocks of ribbon chert, including Lower to Middle Triassic chert, also entered into this depositional site.

When the oceanic plate reached the subduction zone, or near to it, terrigenous matters covered the siliceous mudstone of the Minamikawame, middle Komatsugura, Sambotoji, Shimochi, Nagaiwamori, Sippyou, Kotanichi, and Shiraitotaki Subcomplexes, and the chert-clastics sequence of the Okudaira, Fukushi, Furuyadomori, and Yasomori Subcomplexes. In particular, manganese-ore deposits of the Sippyou and Furuyadomori Subcomplexes also appeared under low radiolarian productivity conditions at a lower latitude. Small amounts of siliciclastic sandy grains of dissected magmatic arc provenance covered the mudstone in the Tanesashi and Kitakawame Complexes, in the Taguri and Sippyou Subcomplexes of the Tsugaruishi Complex, and in the Kotanichi and Shiraitotaki Subcomplexes of the Karomori Complex, probably in the Middle-Late Jurassic.

Based on the mineral composition of sandstone, the major provenance of siliciclastic sediment of the study area may be a dissected magmatic area. However, the suggested provenances of the depositional sites differ among the complexes or subcomplexes : (1) A large amount of siliciclastic sediment was deposited on an unknown basement as a source of the Kariya Subcomplex, where granitic, rhyolite basement rocks, and an accretionary complex are exposed as a minor element of the provenance. (2) Siliciclastic sediments deposited probably on a single depositional site as a source of the Okudaira, Fukushi, and Furuyadomori Subcomplexes. The siliciclastic sediments change from mudstone with a few sandstone layers of the Okudaira Subcomplex, through parallel-laminated mudstone of the Fukushi Subcomplex, to the sandstone-dominant alternating sandstone and mudstone of the Furuyadomori Subcomplex. Chert breccias occasionally flowed into the depositional part of the Fukushi and Furuyadomori Subcomplexes during siliciclastic sedimentation. (3) Siliciclastic sands with rip-up clasts were also supplied from an unknown source into depositional sites of the Choukomori and Yasomori Subcomplexes. The original relationships among these three provenances of siliciclastic rocks are unknown.

A set of fragments of the limestone-greenstone complex, pelagic sequences, and clastic rocks have been accreted along the eastern margin of the East Asia continent from the Middle Jurassic to the earliest Cretaceous. In the early phase of accretion, intrafolial folding, as in the Fukushi Subcomplex, developed. Imbricate structures, each set consisting of a sequence from ribbon chert to clastic rocks, were formed during accretion. Since the consolidation of these accreted sediments, melanges formed as the Tanesashi Complex, followed by the folding of this complex. Faulting systems created the major tectonic framework of the Tanesashi, Kariya, Kitakawame, Tsugaruishi, and Karomori Complexes. Collision of the Kuzumaki-Kamaishi Subbelt with the South Kitakami Belt strongly deformed the Kuzumaki-Kamaishi Subbelt, and mappable NW-SW to NNW-SSE trending folds and faults were formed (e.g. Kanisawa and Ehiro, 1986). The deformation is rather significant in the Kitakawame and Takatakimori Complexes. Relatively tight folds formed in the Kitakawame Complex, and strong slaty cleavage developed in the Takatakimori Complex. On the other hand, deformation is not remarkable in the Tanesashi, Tsugaruishi, and Karomori Complexes ; subcomplexes in these complexes have only gentle folds at a mappable scale. Slaty cleavage in the Takatakimori Complex probably formed in the earliest Cretaceous (e.g. Kanisawa and Ehiro, 1986). According to Kanisawa and Ehiro (1986), the early phase of porphyrite activities started prior to development of the slaty cleavage, and the Early Cretaceous plutonic rocks intruded in the Kuzumaki-Kamaishi Subbelt between 110-120 Ma. Northeast-trending vertical faults developed in this region before deposition of the late Early Cretaceous Miyako Group. In addition to this tectonic history, the Oshima Orogeny (Kobayashi, 1941) had multiple tectonic events that occurred after the collision of the Kuzumaki-Kamaishi Subbelt and South Kitakami Belt and before the development of NE-trending vertical faults.

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