CHAPTER III

GEOLOGY OF THE SOUTHERN KITAKAMI AREA

Non-metamorphosed Paleozoic sedimentary rocks in the Southern Kitakami area were firstly studied by Jimbo about a century ago (Minato, 1979). He collected certain Permain fossils here, which were later introduced by Harada (1890) in his monograph "Die japanischen Inseln". Next, Yabe extensively studied the Paleozoic rocks in cooperation with many of his students, such as Hayasaka, Hanzawa, Mabuti, Sugiyama, Endo, Noda, Onuki, and others. The major divisions of Paleozoic sedimentary rocks were, thus, established by the 1930's (Minato, 1979). Later on, Minato together with his students began to carry out detailed stratigraphy of Paleozoic rocks in the Southern Kitakami area. Stratigraphical account of the Silurian to Lower Carboniferous strata in the Hikoroichi district was reported as preliminary notes by Yabe and Sugiyama in 1937 and 1938 (Kato and Minato, 1979). After that, both Paleozoic and Mesozoic sedimentary rocks in the Southern Kitakami area have further studied continuously by several geologists. The detailed geology of this area is presented below.

Southern Kitakami area comprises mostly Paleozoic and Mesozoic strata underlain by granites and ultramafic igneous complexes. These two igneous types are inferred to be the pre-Silurian rocks of the area (Kawamura *et al.*, 1990). Silurian and Devonian rocks of the Southern Kitakami area distribute in the very narrow and limited areas. They are frequently observed to associate with the above supposed pre-Silurian rocks. Carboniferous and Permian strata, on the other hand, are the major rocks occupying most parts of the area, especially the central part. Mesozoic strata of this area are distributed dominantly along the coast, especially in the southern part. These Paleozoic and Mesozoic strata are represented by clastic, carbonate, and

pyroclastic rocks of mostly shallow marine facies. Besides, there are also some volcanic and plutonic rocks occur sporadically as small isolated bodies associated with those sedimentary strata. Early Cretaceous granites are the most common igneous rocks that took place in this area. Geologic map and standard succession of the pre-Tertiary sequences of the Southern Kitakami area are shown in Figure 3.1 and Table 3.1 respectively. Stratigraphy of this area described below are based mostly upon Kimura *et al.* (1991). Detailed geology of Devonian, Carboniferous, and Triassic periods was more emphasized herein than the others due to the fact that detrital chromian spinels were discovered by the author from clastic sedimentary rocks.

3.1 Pre-Silurian

Up to the present, ages of the Japanese rocks older than Silurian are still doubted among geologists. They exposed generally in the specific narrow and limited areas. In Southern Kitakami, inferred pre-Silurian rocks existed only along or very near the tectonic lines or faults (see fig. 3.1). Essential groups of rocks are Hayachine ultramafic complex (Ordovician) which existed along the Hayachine fault in the northernmost part of the area, Miyamori ultramafic complex along the Hizume fault in the northwestern part, ultramafic associating with the Motai metamorphic complex at Nagasaka district in the west just below the Miyamori ultramafic complex, and granites (Hikami Granites) at Ofunato City in the east between the above two faults (Fig. 3.1).

Originally, ultramafic rocks of both Hayachine and Miyamori complexes are very similar to each other, they are mostly harzburgite and dunite, eventhough the Hayachine complex had been then serpentinized and suffered a contact metamorphism (Fujimaki and Yomogida, 1986). From geologic features and petrologic similarities of ultramafic rocks between Hayachine and Miyamori complexes, Ozawa (1988) suggested that they were formed very near to each other as a thrust sheet emplaced

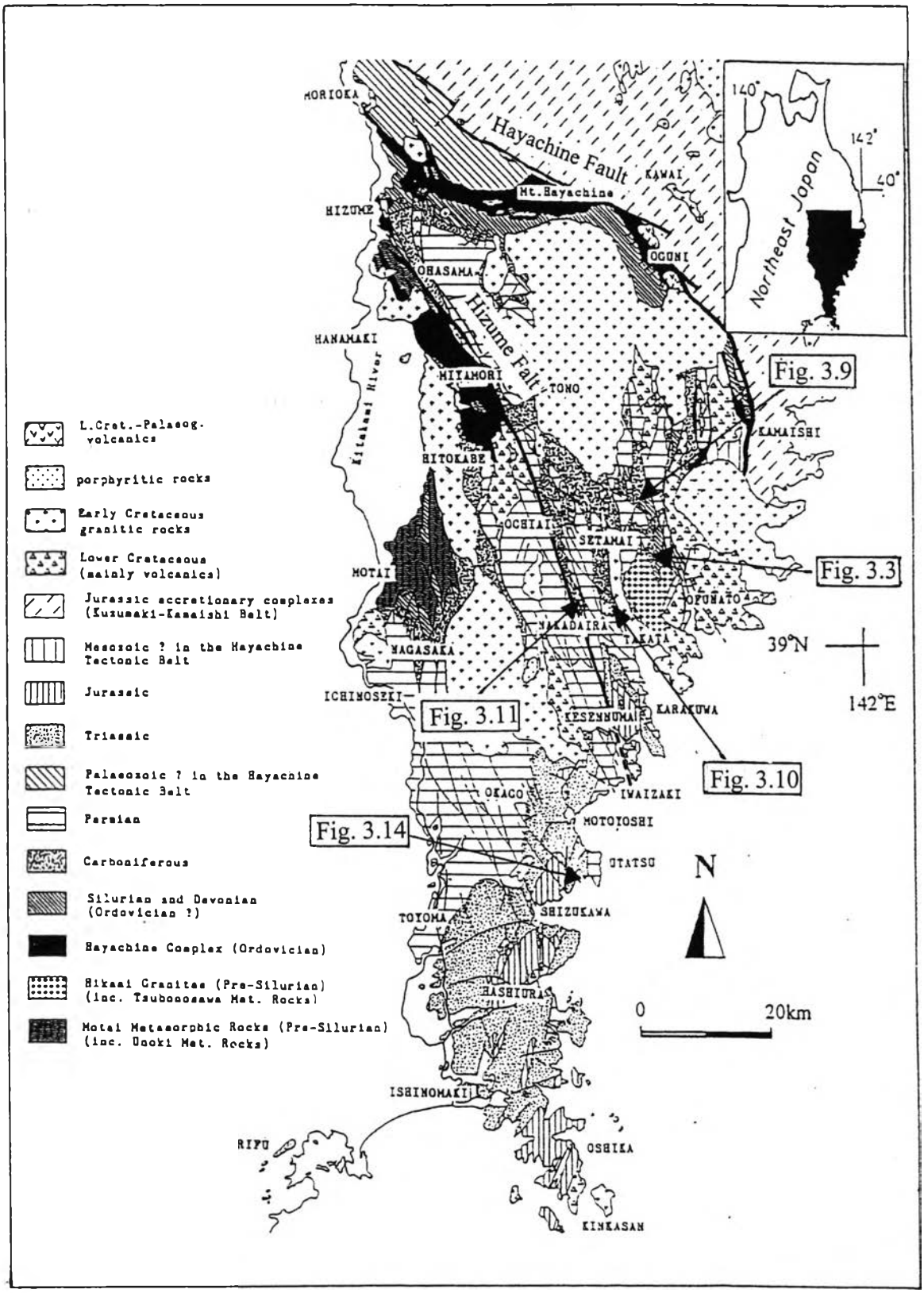


Figure 3.1 Geologic map of the Southern Kitakami area (Mori *et al.*, 1992).

Table 3.1 Standard succession of the pre-Tertiary sequences in the Southern Kitakami area (Mori *et al.*, 1992).

Cretaceous	E	granitic rocks		
		Oshima Group, Ofunato Group etc.		
		Jusanhama Group		Karakuwa & Oshika Group
Jurassic	L ⟩ M	Hashiura Group	Sodenohama F.	
			Arato Form.	
			Aratozaki F.	
	E	Shizukawa Group	Hosoura F.	
			Niranohama F.	
Triassic	L	Saragai Group	Chonomori F.	
			Shindate F.	
	M	Inai Group	Isatomae Formation	
			Fukkoshi Formation	
	E		Osawa Formation	
			Hiraiso Formation	
Permian	L	Toyoma Formation		
	M	Kanokura Formation		
	E	Sakamotozawa Formation		
Carboniferous	L			
	E	Takezawa Formation	Nagaiwa Formation	
			Onimaru Formation	
		Karaumedate Formation	Odaira Form.	Hikoroichi Formation
			Arisu Form.	
			Shittakazawa F.	
Devonian	L	Tobigamori F.		
	M ⟩ E	f	Nakazato Formation	
			Ono Formation	
Silurian			Kawauchi Formation	
Ordovician ⟩ Cambrian		f	Hikami Granites	
		Motai Met. Rocks		

along the Hayachine tectonic belt in Odovician. Later tectonic events in the Cretaceous led to the transportation of the Miyamori complex southwards along the Hizume-Kesennuma sinistral transcurrent fault.

3.2 Silurian and Devonian

Although Silurian and Devonian rocks of Japan are restricted in a few places, they usually exist together. Silurian fossils were firstly discovered (Onuki, 1937) four years after the discovery of Devonian fossils by Yabe and Noda (Kimura *et al.*, 1991) in the Southern Kitakami area. Since then, other Silurian and Devonian rocks of Japanese Islands were continuously investigated by many geologists throughout the country. Successions of Silurian and Devonian sequences in the Southern Kitakami area are shown in Table 3.2.

In the Southern Kitakami, the formations of Silurian and Devonian periods are typically distributed in Hikoroichi and Setamai districts, where they cover the supposed pre-Silurian granites unconformably. Siluro-Devonian rocks are also distributed in contact with ultramafic rocks at the Hayachine tectonic fault, and in small places associated with Motai matamorphic rocks in Nagasaka district (Fig. 3.1).

In Hikoroichi and Setamai districts, near the Ofunato City, Silurian and Devonian are composed of Silurian Okuhinotsuchi and Kawauchi Formations and Devonian Ono and Nakazato Formations. The Okuhinotsuchi Formation (Kawamura, 1983) in Setamai district covers the supposed pre-Silurian granite unconformably, and is classified as having lower and upper members. The lower member (more than 40 m thick) is made up of a probable terrestrial mudstone, welded medium and acid tuff, arkosic sandstone, and alternating beds of tuffaceous sandstone, tuff, and impure limestone. The upper member (more than 50 m thick) is mainly dark gray, bedded

Table 3.2 Successions of Silurian and Devonian sequences in the Southern Kitakami area (Kimura *et al.*, 1991).

Ages \ Localities			Nagasaka	Setamai	Hikoroichi	Hayachine Kamaishi
Devonian	Late	Famennian	Tobigamori F.			Senjogataki F.
		Frasnian	?			
	Middle	Givetian				
		Eifelian		Nakazato F.		
	Early	Emsian	Motia G.			
		Siegenian		Ono F.		
		Gedinnian	?	(Takainari)		
Silurian	Late	Pridolian				?
		Ludlovian				
	Early	Wenlockian		Kawauchi F.		Orikabetoge F.
		Llandoverian		Okuhino-tsuchi F.		?

limestone with breccias of welded tuff or thin layers of tuffaceous sandstone at some horizons. Lower part of the lower member yeilds *Favosites* sp. and *Encrinurus* sp., and its upper part *Halysites* cf. *cratus*, *Favosites* sp. and other fossils. Lower part of the upper member yeilds *Halysites labyrinthicus, H. arisuensis,* and the middle part *Falsicatenipora shikokuensis.* The strata at Kamiarisu district that are correlated with the Okuhinotsuchi Formation yeild a Silurian brachiopod, *Pentamerus* sp. (Tazawa *et al.*, 1984).

Silurian and Devonian formations in the Hikoroichi district form an anticlinorium with strata from the Carboniferous to Early Cretaceous. The Silurian Kawauchi Formation (less than 100 m thick) is younger in most parts than the Okuhinotsuchi Formation in the Setamai district. It is composed of basal conglomeratic sandstone and an overlying limestone with intercalations of mudstone (Onuki, 1969). More than 75 spicies of fossils have been discovered by Kato (1979), thay are of corals such as *Favosites gotlandicus gotlandica, Schedohalysites kitakamiensis, Falsicatenipora japonica, Halysites labyrinthicus, Nipponophyllum giganteum*; brachiopods such as *Skenidioides kitakamiensis*; trilobites such as *Encrinurus kitakamiensis*; and stromatoporoids, bryozoans, and calcareous algaes.

The Devonian Ono Formation with the thickness of 500 m is composed of lower, middle and upper members. The lower part of the lower member is composed of purple-red or dark green muddy-strata that once was called the Takainari Formation. The upper part of this lower member is composed of tuff, tuffaceous sandstone and mudstone, as well as tuffaceous limestone that intercalated with breccias layer. This breccias layer contains granite blocks, some of which are more than 3 m in diameter. The tuffaceous limestone yeilds the corals, *Xystriphyllum interlineatum, Spongophyllum halysitoids, Favosites cf. pseudosocialis,* and *Ohnopora hayasakai,* but no halysitids. Its middle member is composed of alternating beds of sandstone and

mudstone with several vitric tuff layers, yeilds *Ohnopora hayasakai*, Its upper member is formed of acid tuff, keratophyre, and dacite.

The Nakazato Formation covers the Ono Formation conformably (Figs. 3.2). Andesitic and rhyolitic volcanism was very active in the Ofunato City during the depositional stage of these formations. Its lower part is composed mainly of basic tuff with some muddy layers. The middle part has alternating beds of black mudstone and acid tuff. The upper part has alternating beds of sandstone which contains many detrital chromian spinels and mudstone with thin fossil layers that yeild the trilobites, *Thysanopeltella (Septimopeltis) paucispinosa, Dechenella (Dechenella) minima* (Kobayashi and Hamada, 1977); the brachiopods, *Atrypa (Planatrypa) japonica* (Copper *et al.*, 1982), *Zdimir* sp. (Tazawa, 1988); as well as corals and terrestrial plant fossils. The fossil remains date to the upper Eifelian. Location of detrital chromian spinels found in sandstone of the upper Nakazato Formation is shown in Figure 3.3. Figures 3.4 and 3.5 illustrate nature of outcrops of the Nakazato Formation in the Hikoroichi district.

In the Hayachine tectonic zone, fossils that have been reported from strata on the southern side of the ultramafic complex are a Silurian coral, *Halysites kuraokensis*, near Ohasama district, from the Orikabetoge Formation (Kawamura *et al.*, 1984); a Silurian brachiopod, *Trimerella*, south of the Hayachine mountain (Ehiro *et al.*, 1986), and an upper Devonian plant, *Leptophoeum rhombicum*, from the Senjogataki Formation to the west of Kamaishi (Okami *et al.*, 1987). Silurian sandstones in Ohasama district were discovered to contain detrital chromian spinels by Yoshida *et al.*, 1995. Devonian Senjogataki Formation in the Hayachine zone was also constituted from sandstone that contains detrital chromian spinels (Hisada *et al.*, 1995).

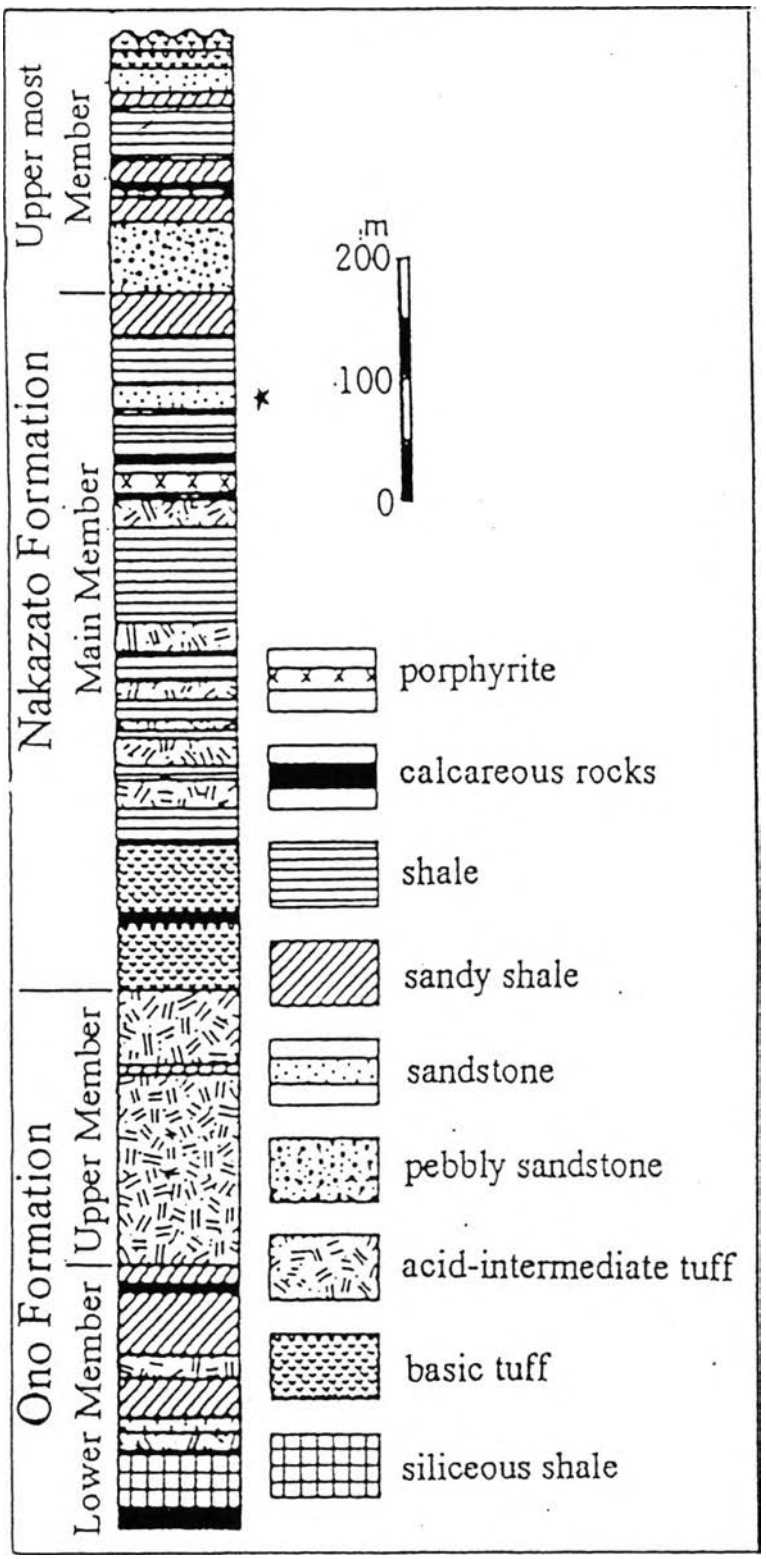


Figure 3.2 Columnar section of Lower to Middle Devonian rocks in Hikoroichi district (Oide, 1989). ★ is the bed with detrital chromian spinel.

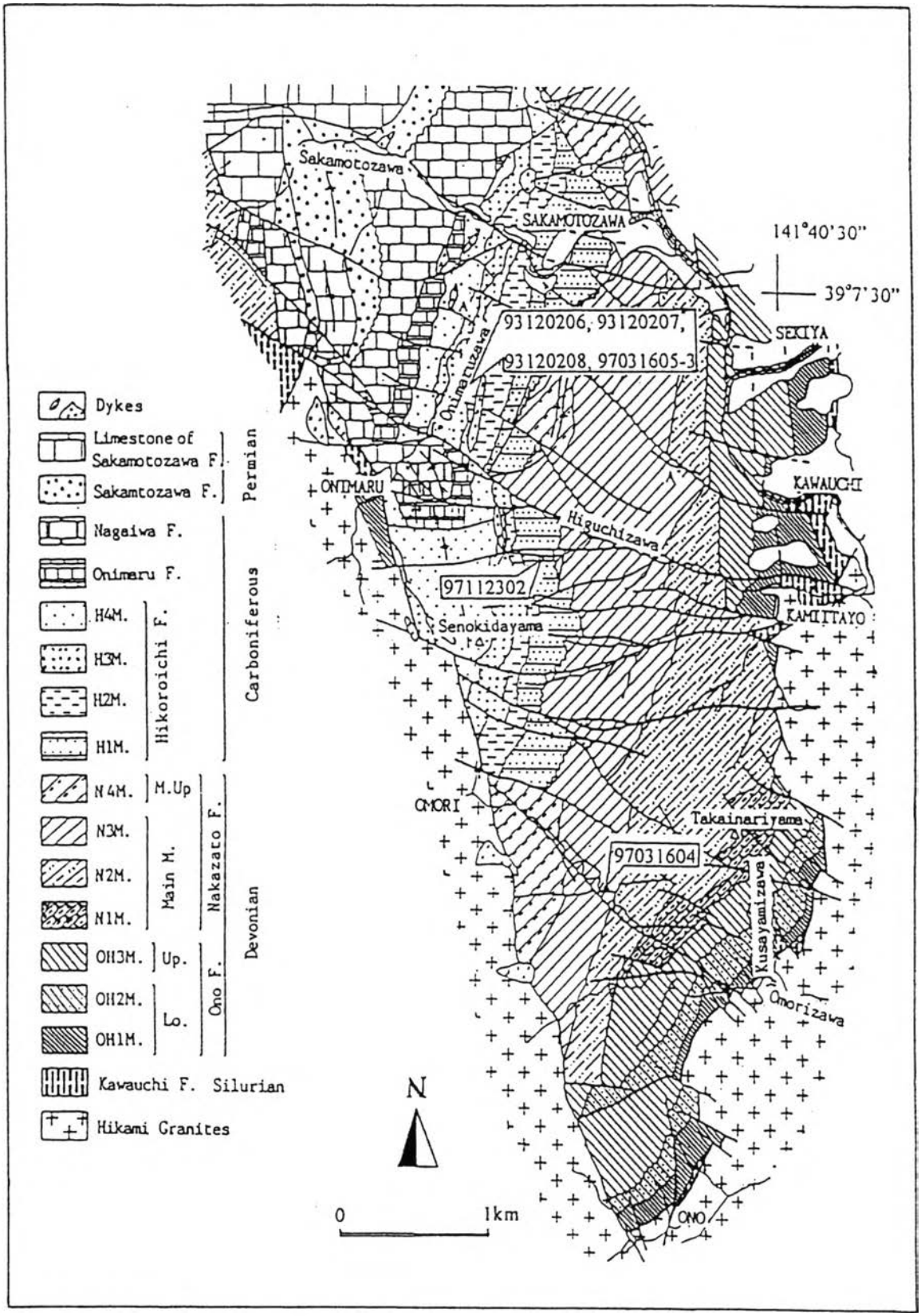


Figure 3.3 Geologic map of the Hikoroichi district (Mori *et al.*, 1992). Locations where detrital chromian spinels were found is shown by the numbers of sandstone samples.

Figure 3.4 Well-bedded fine-grained greenish gray sandstone of the Devonian Nakazato Formation showing the very deep dipping at Hikoroichi district.

Figure 3.5 Thick beds of very fine- and fine-grained greenish gray sandstones of the Devonian Nakazato Formation in Hikoroichi district.

In Nagasaka district, stratigraphic successions of the Upper Devonian and older strata differ markedly from those of the Silurian and Devonian formations in the Hikoroichi and Setamai districts. Upper Devonian formations of the former, overlying with conformity or weak unconformity the partly metamorphosed Motai Group, are composed of clastic rocks, submarine basic volcanic rocks, and submarine sliding breccias with serpentinite blocks. Here, the older geosynclinal basin had become a shallow-water area in the Late Devonian Period.

The lower part of the Tobigamori Formation in Nagasaka district, about 330 m thick, is comprised mainly black mudstone with subordinate sandstone containing detrital chromian spinels (Hisada *et al.*, 1997) and tuff. The middle part is composed of black mudstone that intercalates the Nutsuyama tuffaceous conglomerate, which yields fragments of crystalline schist. The upper part is composed of black mudstone that has conglomerate and tuff layers. The middle and upper part yield *Cyrtospirifer yabei, C. tobigamoriensis* and other brachiopods (Noda and Tachibana, 1959), which show the age of Famennian. The Tobigamori Formation also has the *Leptophoeum rhombicum* flora, indicating the age of Late Devonian (Hisada *et al.*, 1996).

3.3 Carboniferous

Carboniferous strata are distributed in the Kamaishi, Hikoroichi-Setamai, and Nagasaka districts. Their distribution is nearly the same as that of the Devonian strata (Fig. 3.1). The Carboniferous formations have been studied in most detail in the Hikoroichi and Setamai districts, and have been classified in ascending order as the Hikoroichi, Arisu, Odaira, Onimaru, and Nagaiwa Formations (Onuki, 1969). The upper part of the Hikoroichi Formation at the type locality, however, has proved to be correlated to the Odaira Formation in the Setamai district because of the occurrence of lower Visean corals and Brachiopods (Mori and Tazawa, 1980). The Shittakazawa,

Arisu, and Odaira Formations in Setamai were correlated to the Hikoroichi Formation in Hikoroichi district (Kawamura, 1985). Successions of Carboniferous sequences in the Southern Kitakami area are shown in Table 3.3 and Figure 3.6.

The Shittakazawa Formation, about 700 m thick, covers the Devonian strata unconformably, and is composed mainly of mudstone, sandstone, arenaceous limestone, and acid tuff. The acid tuff intercalates at places a conglomerate layer that contains granitic rocks and welded tuff as clastic fragments. The formation yields *leptagonia analoga, Spirifer ultratransversa, Schizophoria resupinata pinguis, Palaeosmilia membiensis, Kitakamithyris tyoanjiensis* and other fauna fossils (Kawamura, 1985; Tazawa and Kurita, 1986).

The lower part of the Hikoroichi Formation shows good exposures (see Figs. 3.7 and 3.8) has a similar lithologic succession to the Shittakazawa, and overlies unconformably the middle Devonian Nakazato Formation. Detrital chromian spinels were detected from sandstone and siltstone at many localities of this formation (see Figures 3.3 and 3.9). Fossils of about 80 spicies (e.g., *Kitakamithyris tyoanjiensis, K. hikoroichiensis, Leptagonia analoga, L. covexa, Actinoconchus planosuleata, Delthyris clarksvillens, Syringothyris transversa, Phillipsia ohmoriensis* and *Eostrotion*) have been reported from the lower part of the Hikoroichi by Sugiyama (1944), Sakagami (1962), Minato and Kato (1977), Kobayashi and Hamada (1980), and others. The lower part was firstly correlated to the upper Tournaisian on the basis of the presence of *Caninia cornucopiae, Palaeosmilia* sp., *Cyathaxonia* sp., and *Amygdalophyllum* sp.

The Arisu Formation, 350-700 m thick, is composed of basaltic pyroclastic rocks, mudstone, tuffaceous sandstone, and arenaceous or tuffaceous limestone. The basaltic pyroclastic rocks at the lowest horizon of the formation are more than 200 m

Table 3.3 Successions of Carboniferous sequences in the Southern Kitakami area (Kimura *et al.*, 1991)

Ages \ Localities		Nagasaka	Hikoroichi	Setamai	Kamaishi
Carboniferous	Gzelian				
	Kasimovian				
	Moscovian				
	Bashkirian	Takezawa F.	Nagaiwa F.	Nagaiwa F.	
	Sperpukhovian				
	Visean		Onimaru F.	Onimaru F.	Kogawa F.
	Tournaisian	Karaumedate F.	Hikoroichi F.	Odaira F.	
				Arisu F.	
				Shittakazawa F.	

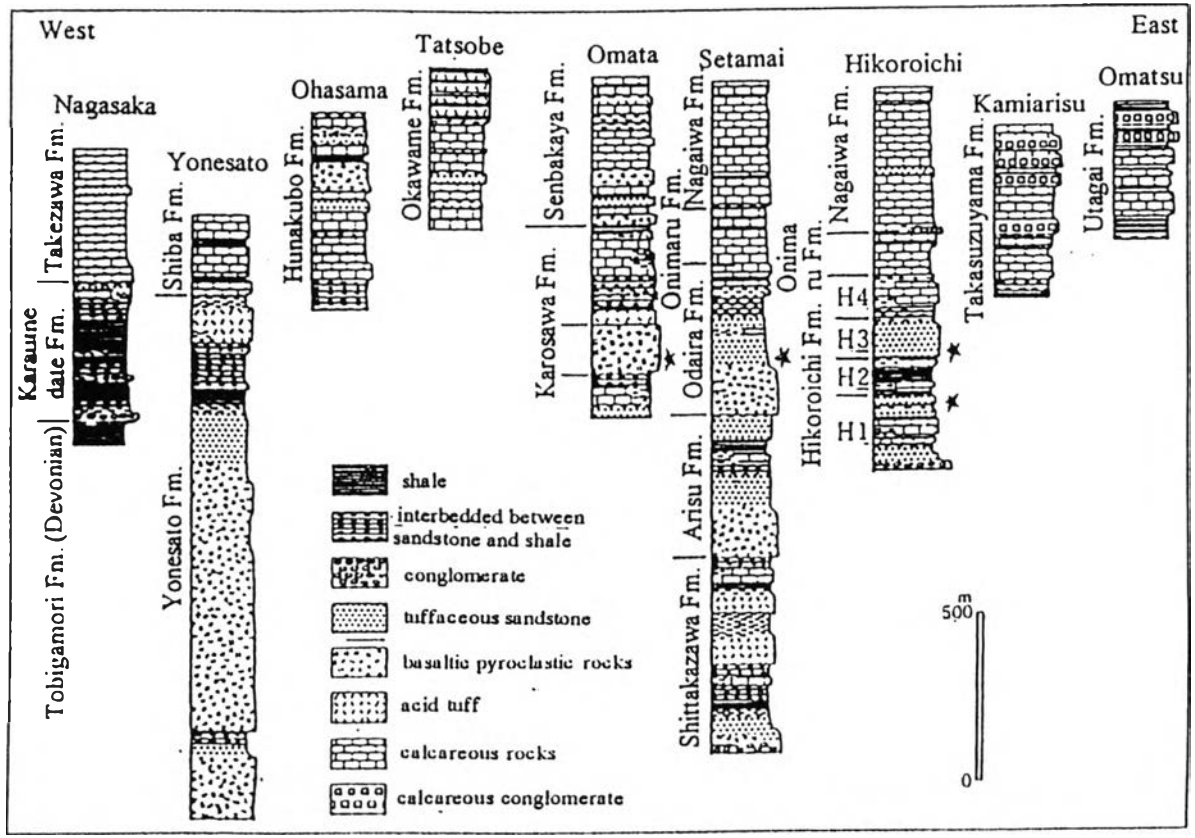


Figure 3.6 Columnar sections of Carboniferous rocks in the Southern Kitakami area (Oide, 1989). ✶ is bed that found detrital chromian spinel grain(s).

Figure 3.7 Large exposure of calcareous fine-grained sandstones and siltstones of the Carboniferous Hikoroichi Formation with deep dipping at the Onimaru quarry in Hikoroichi district.

Figure 3.8 Fine-grained sandstone in the lower part of the Carboniferous Hikoroichi Formation at Hikoroichi district.

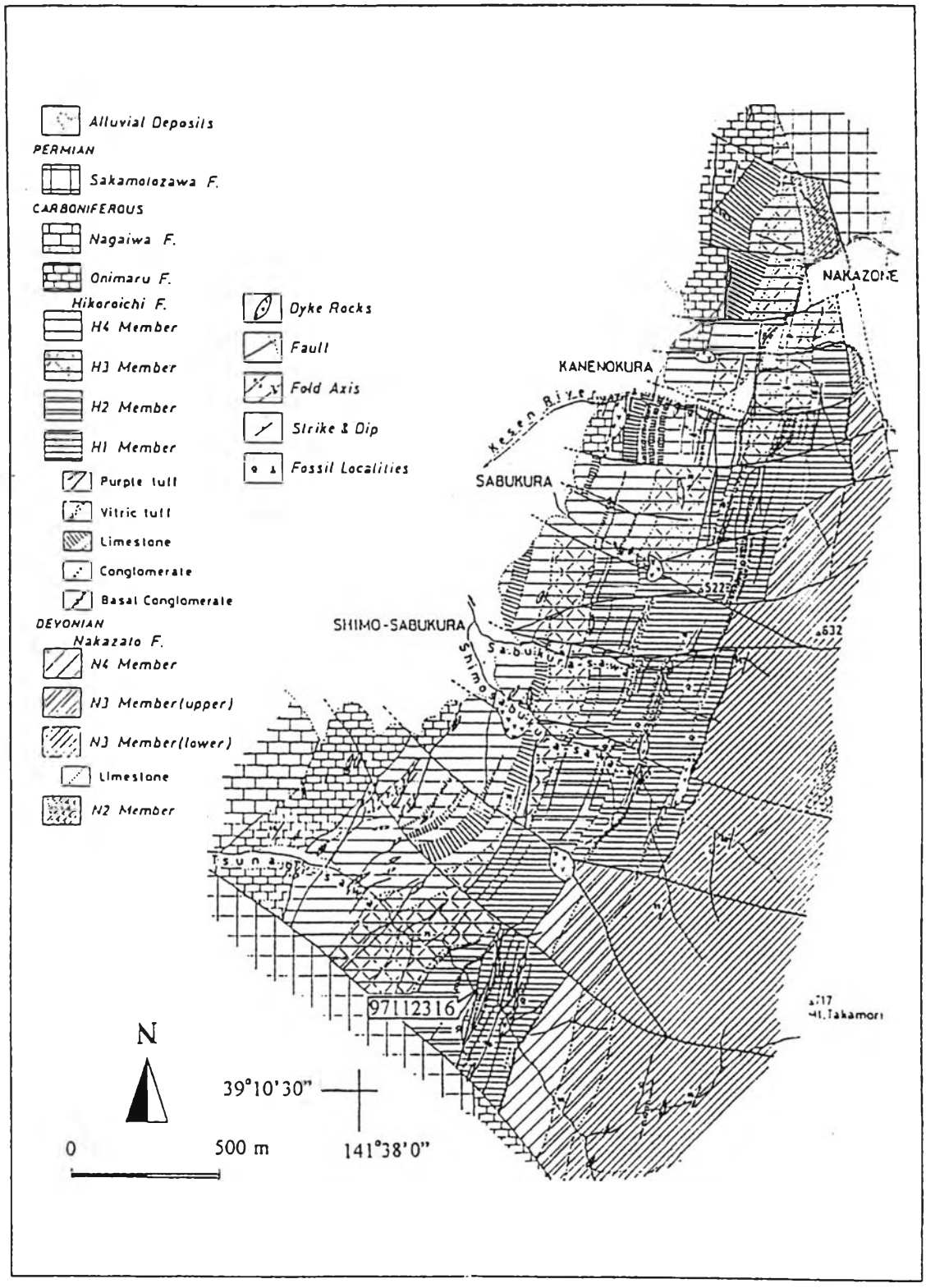


Figure 3.9 Geologic map of the Sabukura district (Kawamura, 1983). Location where detrital chromian spinels were found is shown by the number of sandstone samples.

thick in places, but thin out towards the north. The formation is correlated to the upper Tournaisian by the existence of *Amplexus nipponensis, Syringothyris jumonjiensis, S. kitakamiensis, S. transversa, Kitakamithyris semicircularis, Spirifer kozuboensis*, and other fauna fossils (Minato *et al.*, 1953).

The Odaira Formation is about 600 m thick at the type locality. Its lower part is composed of basaltic pyroclastic rocks and lava with the intercalation of volcanic conglomerates, and its upper part is composed of mudstone, sandstone, and oolite-bearing arenaceous limestone. Sandstone of this formation was also found to contain detrital chromian spinels (see Figure 3.10 for the location). *Sukiyamaella carbonarium* and *Schizophoria resupinata* have been reported from this formation and, recently, from the upper part *Pseudouralinia tangpakouensis, Kueichouphyllum heishihkuanense* and *Yuanophyllum kansuense* which are characteristic corals of Southern China assigned as the upper Visean (Kawamura *et al.*, 1985).

The upper part of the Hikoroichi Formation has a stratigraphic succession similar to that of the Odaira Formation and yields *Amygdalophyllum etheridgei, Koninckophyllum* sp., and *Schizophoria resupinata.* These fossils show that the Hikoroichi Formation is not limited to the Tournaisian, the upper part extends to the Visean. This upper part also yields plant fossils such as *Archaeocalamites scrobiculatus,* which has been reported from the Early Carboniferous in China (Asama *et al.*, 1985).

The upper Visean Onimaru Formation in Hikoroichi district overlies the upper part of the Hikoroichi Formation conformably. It is about 75 m thick and composed principally of dark gray or black limestone with intercalation of thin mudstone and calcareous sandstone layers. The Onimaru Formation yields abundant coral fossils that are also found in South China.

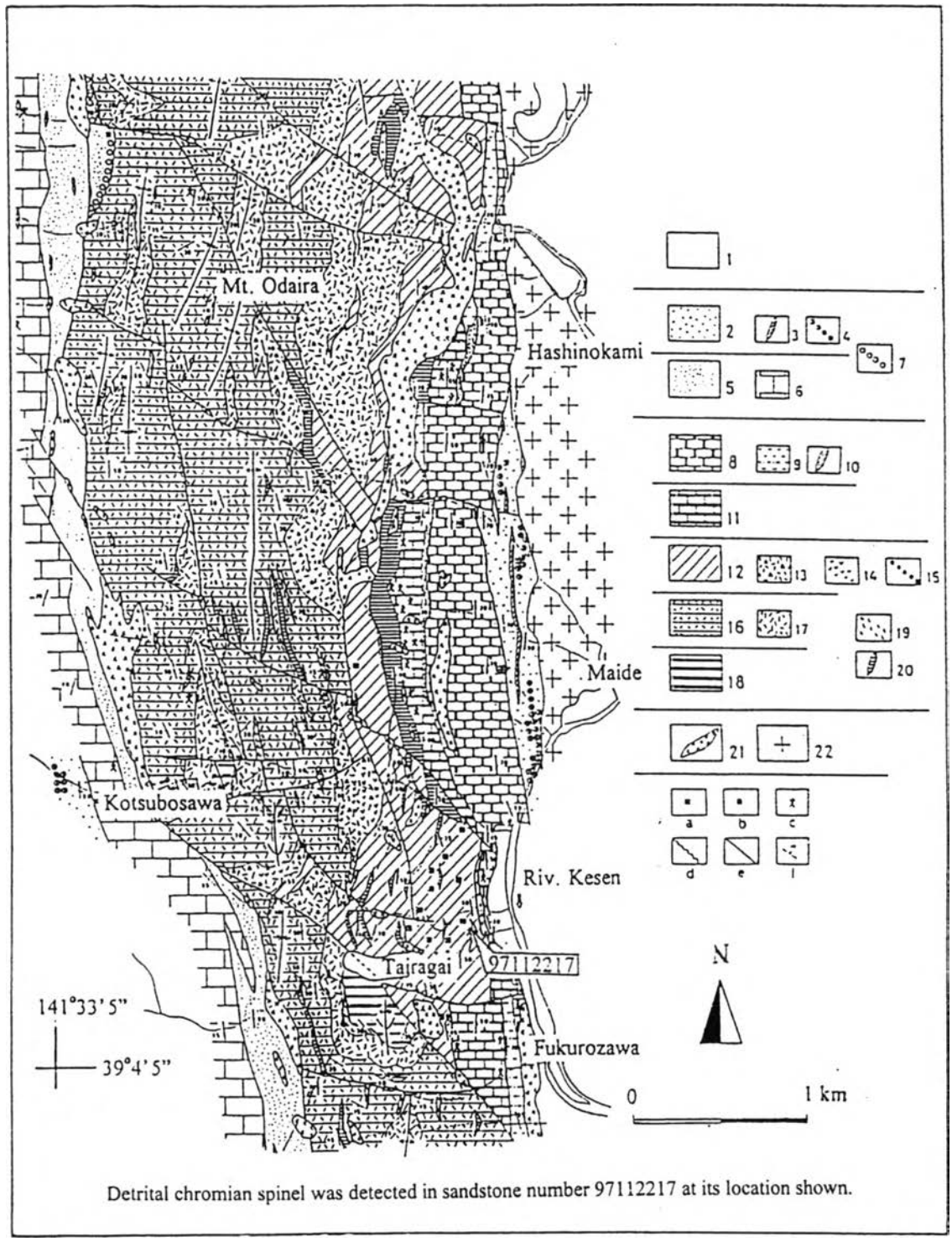


Figure 3.10 Geologic map of the Yokota district (Kawamura, 1983).

1: Quaternary deposits. 2—4: Middle Permian Kanokura Formation (2: alternation of sandstone and slate, 3: limestone, 4: "Usuginu-type" conglomerate). 5, 6: Lower Permian Sakamotozawa Formation (5: alternation of sandstone and slate, 6: limestone). 7: conglomerate of the Permian Formations excluding "Usuginu-type" conglomerate. 8—10: Upper Carboniferous Nagaiwa Formation (8: limestone, 9: calcareous slate, 10: basaltic volcaniclastic rocks). 11: Lower Carboniferous Onimaru Formation. 12—15: Lower Carboniferous Odaira Formation (12: alternation of slate, sandstone and volcaniclastic rocks; 13: basaltic volcaniclastic breccia; 14: basalt lava; 15: conglomerate). 16, 17: Lower Carboniferous Arisu Formation (16: alternation of slate, sandstone and volcaniclastic rocks; 17: basaltic volcaniclastic lapillistone). 18: Lower Carboniferous Shittakazawa Formation. 19, 20: intercalations in the Odaira-Shittakazawa Formations (19: acid tuff, 20: sandy limestone). 21: dyke rocks. 22: Cretaceous granitic rock.

a: occurrence of chloritoid, b: occurrence of andalusite (and chloritoid), c: fossil occurrence, d: unconformity, e: fault, f: dip-strike of bedding plane.

The Nagaiwa Formation covers the Onimaru Formation conformably or with paraconformity. At the type locality near Ofunato City, it is about 600 m thick and mainly white limestone with a conglomerate layer constitutes its formation. There are also sandstone layers in the lower part and green tuffaceous layers at some horizons.

Clastic strata that contain a limestone layer of the Kogawa Formation can be correlated with the Onimaru, and Nagaiwa Formations, both distributing near the Kamaishi mine north-northeast of Hikoroichi district along the Hayachine belt. North-northwest of Setamai, near Ohasama district, limestone bodies of the same age are present. Within Ohasama district, west of Setamai, strata are quite similar to those of the Onimaru Formation and the upper part of Odaira Formation. In Nagasaka district, further west of Omata district, the Karaumetate Formation overlies the Upper Devonian Tobigamori Formation conformably or with paraconformity.

The Karaumedate Formation, about 550 m thick, is composed chiefly of sandstone and mudstone. It has been correlated to the Tournaisian Hikoroichi Formation because of the presence of *Kitakamithyris, Syringothyris, Spirifer* cf. *tornacensis* and other fossil fauna. But, like Hikoroichi Formation, it ranged to the upper Visean since the upper Visean brachiopod *Martinia* sp. has been found in its upper part (Tazawa and Osawa, 1979). The Takezawa Formation, which is correlated to the Onimaru and Nagaiwa Formations, comprises mainly limestone and covers the Karaumedate conformably.

At Omata, west of Setamai district, the Karosawa Formation, about 550 m thick, is composed largely of basaltic and pyroclastic rocks, some sandstone and shale, and small amount of limestone beds in the lower part while in the upper part, limestone and sandstone interbedded with shale are much more dominant. Basalt of the lower part is examined to contain abundant chromian spinels, which often occur together

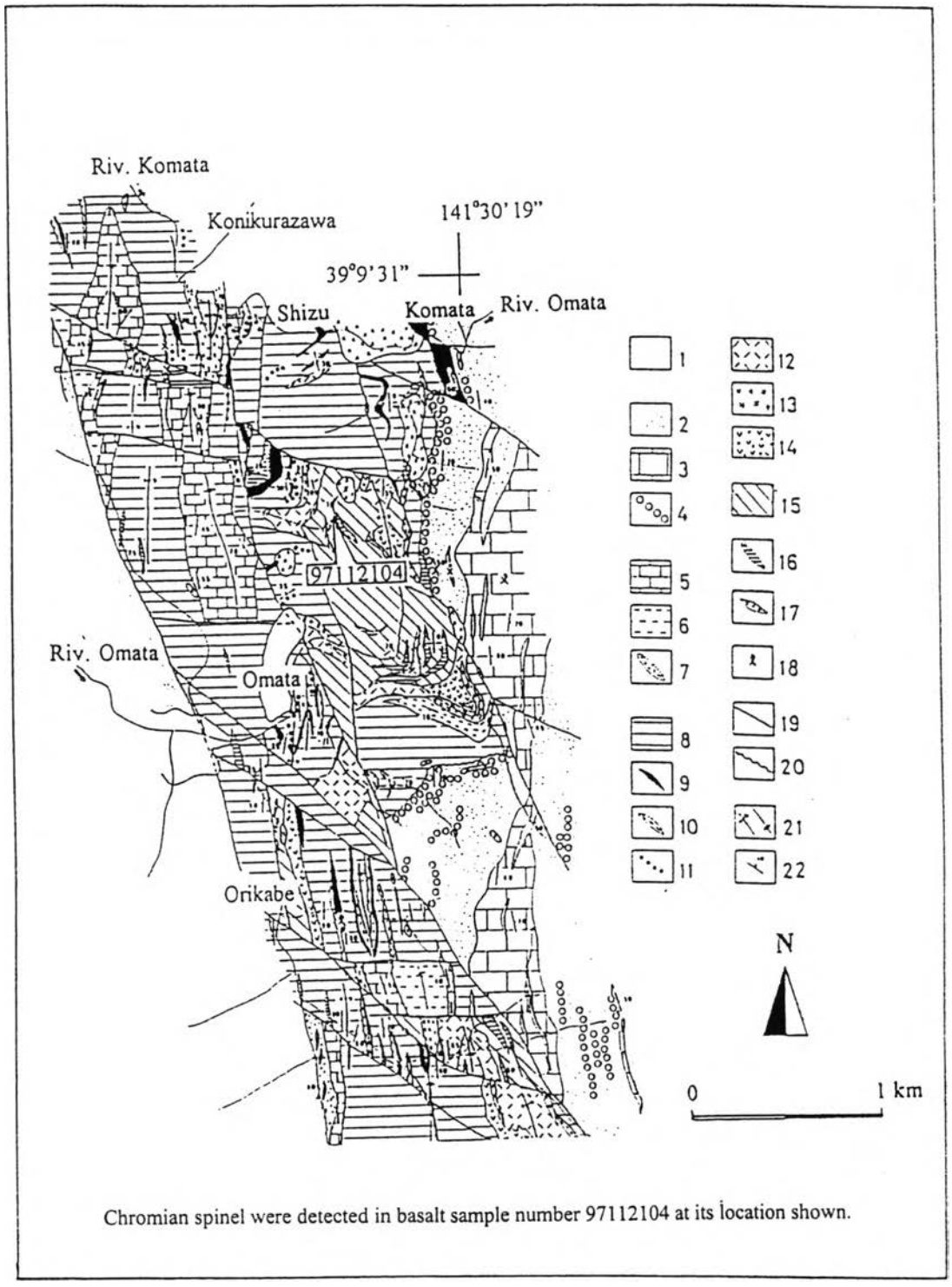


Figure 3.11 Geologic map of the Omata district (Kawamura, 1983).

1: Quaternary deposits. 2-4: Lower-Middle Permian Sakamotozawa and Kanokura Formations (2: alternation of sandstone and slate, 3: limestone, 4: conglomerate). 5-7: Lower-Upper Carboniferous Senbakaya Formation (5: limestone, 6: alternation of slate and limestone, 7: basaltic volcanic rocks). 8-11: Upper Member of the Lower Carboniferous Karosawa Formation (8: alternation of slate, sandstone and volcanicrocks, 9: black limestone, 10: acid tuff, 11: conglomerate). 12-14: Middle Member of the Karosawa Formation (12: basaltic volcanic rocks, 13: purple tuff, 14: basalt lava). 15: Lower Member of the Carboniferous Karosawa Formation. 16: sandy limestone of Karosawa Formation. 17: dyke rocks. 18: fossil occurrence. 19: fault. 20: unconformity. 21: folding axis. 22: dip-strike of bedding plane.

with olivine crystals. Location of this basalt containing chromian spinels is depicted in Figure 3.11.

3.4 Permian

The Sakamotozawa and Kanokura Formations belonging to Early Permian and Middle Permian, respectively, are well developed in the northeastern part of the Southern Kitakami area. They are correlated with the Nishikori, Rodai, Tenjinnoki, and Yamazaki Formations in the northwestern part. The Late Permian Toyoma Formation is wildly distributed in the southern part. Successions of Permian sequences in the Southern Kitakami are shown in Table 3.4.

The Sakamotozawa Formation covers the underlying strata at different horizons with paraconformity or weak angular unconformity. In the Hikoroichi district, at the type locality, the basal part of this formation, about 50 m thick, is composed mainly of basal conglomerate with overlying sandstone and mudstone, which in turn is covered by limestone with the average thickness of 150 m. The clastic strata in the basal part of this formation often contain plant fragments. These strata are rather thick in the Setamai district, where thin seams of coal are intercalated. The limestone is separated into lower and upper sedimentary cycles by a weak erosional unconformity.

The Kanokura Formation has two divisions: a lower part of conglomerate, sandstone, and mudstone; and an upper part of limestone or limestone with mudstone and sandstone. The sandstone of the lower part yields abundant fusuline, brachiopod, trilobite, pelecypod, and gastropod fossils that include *Monodiexodina matsubaishi* and *Leptodus*. The limestone of the upper part, which is sometimes conglomeratic, yields *Lepidolina multiseptata, L. kumaensis* and other fusulines, as well as *Waagenophyllum polyseptata* and other corals. The Kanokura Formation at Iwaizaki

Table 3.4 Successions of Permian sequences in the Southern Kitakami area (Kimura *et al.*, 1991)

Ages \ Localities		Toyoma	Iwaizaki	Ofunato
Permian	Tatarian	Toyoma G.		Toyoma G.
		Yamazaki F.	Iwaizaki Limestone	Kanokura F.
	Kazanian	Tenjinnoki F.		
	Ufimian			
	Kungurian			
	Artinskian	Rodai F		Sakamotozawa F.
	Sakmarian	Nishikori F.		
	Asselian			

district, south of Kesennuma district, is composed almost completely of reef limestone except for its lower part. Strata that are correlated with the Kanokura Formation in Ohasama district, north-northwest of Setamai district, have placer deposits of iron sand with cross stratification.

The Toyoma Group shows its complete succession at the Nabekoshi Mountain, and in Utatsu and Okago districts of the eastern part of the Southern Kitakami area. The very good localities of well-exposed sandstones are along the coast in Utatsu district (Figs. 3.12 and 3.13). At the type locality for its group in the western part, only the lower part is present. The Toyoma Group is composed mostly of black mudstone with coarse clastic strata in its basal part. At the nearly lowest horizon, appear the ammonoids *Xenodiscus* cf. *carbonarius* in the Okago district, and *Araxocerus* cf. *rotoides* and *Protocerus japonicum* together with *Timorites intermedium* in the Utatsu district. *Medlicottia kitakamiensis* occurs in the upper half of the upper part. This upper part of the Toyoma Group also yields small foraminifera, *Colaniella parva-Palaeofusulina* fauna, at Nabekoshi Mountain and in the Utatsu district.

The Nishikori and Rodai Formations, as well as the Tenjinnoki and Yamazaki Formations in western Southern Kitakami area, can be correlated with the Sakamotozawa and Kanokura Formations, respectively. They are rich in clastic rocks, but not in limestone except for upper part of the Rodai Formation. In Towa district, the latter Formation yields Maiya Flora (Asama, 1967) that consist of more than 30 spicies including *Taeniopteris, Cordaites, Zamiopteris.* These fossils belong to the Cathesian flora and have spicies in common with the Shansi series of North China and the Sadong Formation of North Korea. The Tenjinnoki Formation yields *Monodiexodina matsubaishi* as well as *Leptodus richthofeni.*

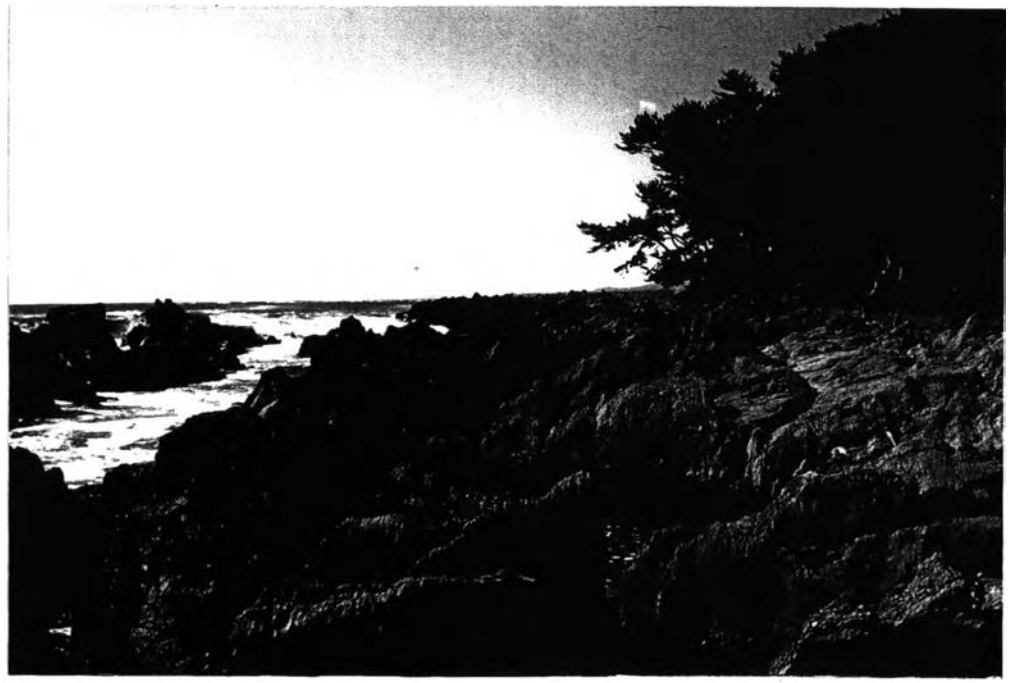


Figure 3.12 Bedded calcareous sandstone of Permian Toyoma Group expose well along the coast in Utatsu district.

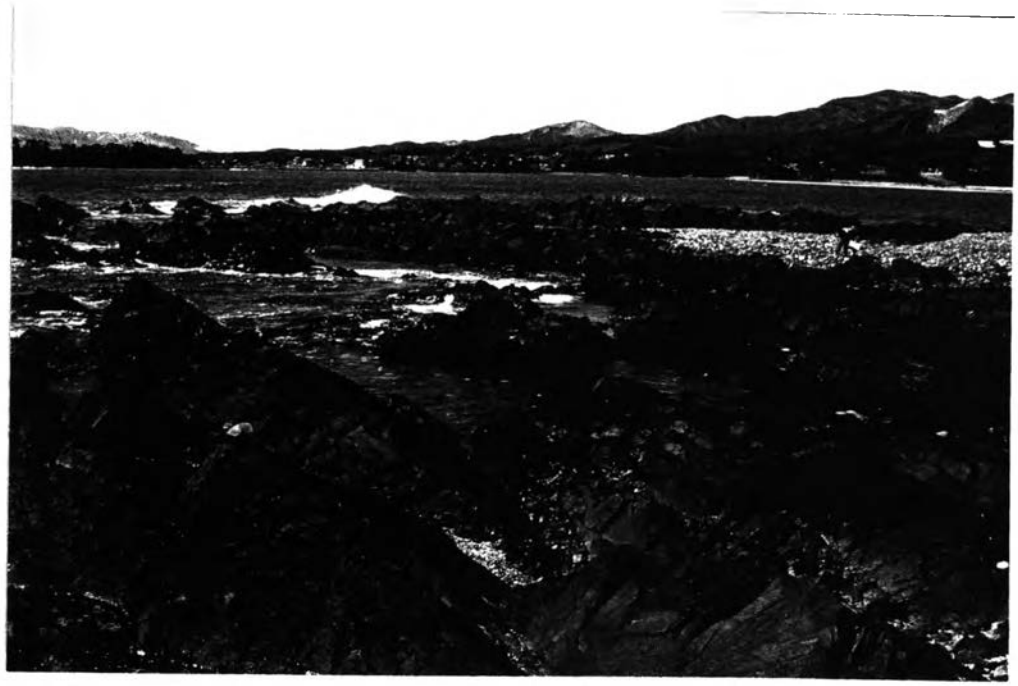


Figure 3.13 Fine- to medium-grained sandstones of Permian Toyoma Group at the south of Utatsu coast.

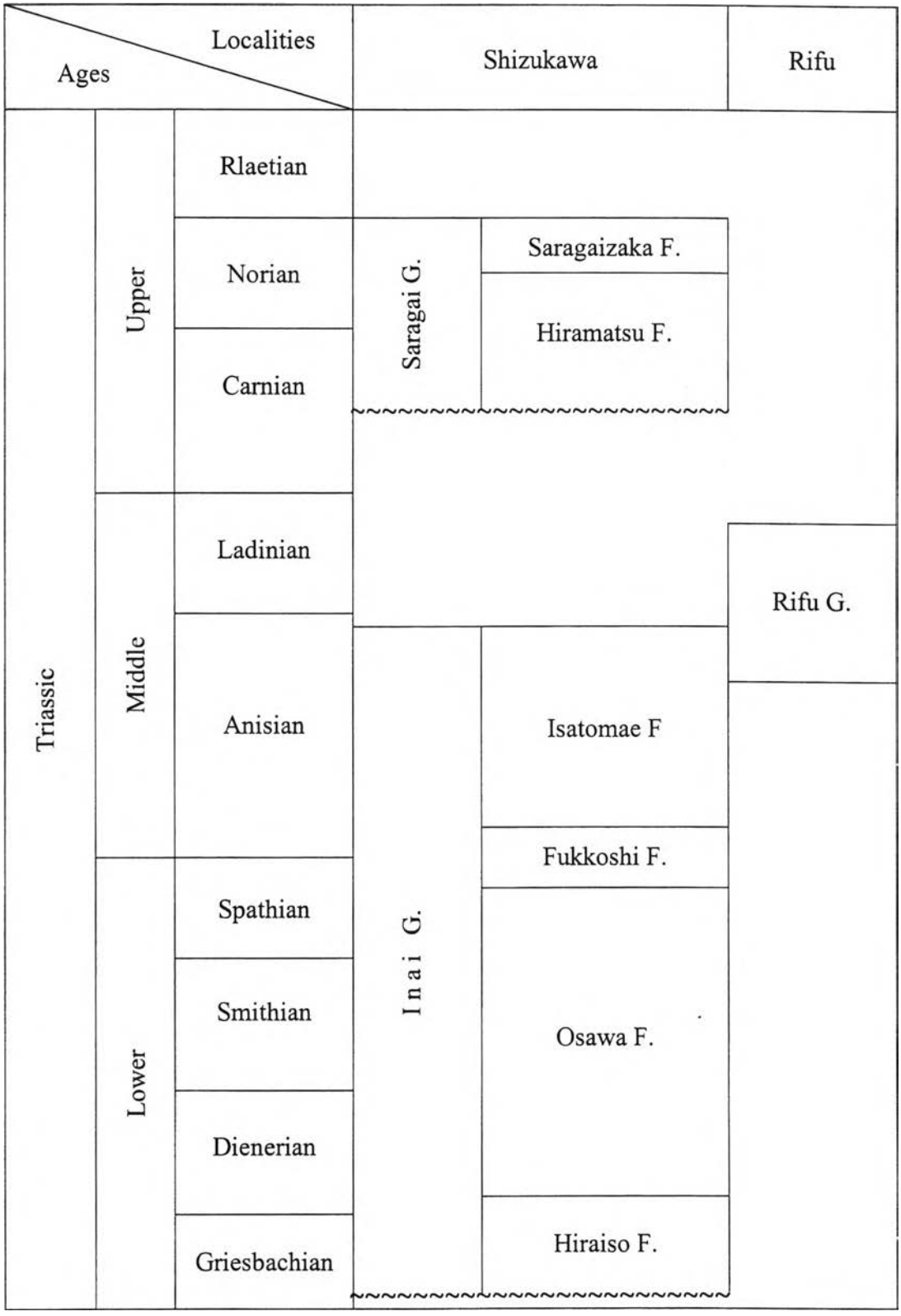
The Toyoma Formation in the western part of the Southern Kitakami area contains Usuginu conglomerate with boulders of granitic rock at its base. Similar conglomerates also appear in the underlying strata, which are collectively called Usuginu-type conglomerate.

3.5 Triassic

In the coastal area of northern Miyagi prefecture, autochthonous marine Triassic formations in the southern part of the area are fairly widely distributed and form several synclines that trend northward together with the underlying and overlying strata. The strata of this area bear abundant megafossils and are regarded as the standard for the Japanese Triassic. Successions of this period in the Southern Kitakami area are shown in Table 3.5.

The Inai Group, not more than 3,000 m thick, rests disconformably on the Upper Permian Toyoma Group, and is composed principally of two sedimentary cycles. The first cycle begins with well-sorted quartzose or calcareous sandstone of a high degree of maturity and merges into characteristic parallel-laminated shale and sandstone. The lower sandy part of the first cycle, the Hiraiso Formation (max. 300 m), yields widely distributed marine bivalves. An early Griesbachian ammonite, *Glyptophiceras*, was found in the lower part of this formation (Bando, 1970). The Upper Griesbachian and Dienerian may be represented by the upper part of this formation but so far have not been indicated by any index fossil. The upper slaty part is called the Osawa Formation, which its maximum thickness is about 200 m and bears *Flemingites, Meekoceras, Xenoceltites?, Danubites, Columbites, Subcolumbites, Eophyllites,* and *Leiophyllites* (Bando and Shimoyama, 1974), which seem to indicate the Smithian and Spathian ages. *Utatsusaurus hataii*, one of the most primitive species of Ichthyosauria, was discovered in this formation (Shikama *et al.*, 1978). Sandstone

Table 3.5 Successions of Triassic sequences in the Southern Kitakami area (Kimura *et al.*, 1991)



existing in this formation, particularly from the lower part, contains some detrital chromian spinels (see Figure 3.14 for the location). The exposures of sandstones in Osawa Formation are shown in Figures 3.15 and 3.16. The lower sandy part of the second cycle, the Fukkoshi Formation (0-500 m), shows remarkable lateral change in lithofacies and thickness, it probably originated from a submarine fan. The overlying Isatomae Formation, 500-1,600 m thick, is also composed of thick parallel-laminated shale and sandstone that bears Anisian ammonites.

The Rifu Group, 500 m thick, near Sendai City, is sometimes regarded as the upper part of the Inai Group based upon its similar lithology, but due to its isolated distribution, the stratigraphic relation is not clear.

The Norian Saragai Group, 250 m thick, appears to cover the Isatomae Formation unconformably and exists in several areas such as Utatsu, Chonomori, and Kesennuma. Its distribution is much narrower than that of the Inai Group. In the type locality (Utatsu), this group is exposed only along the eastern limb of a syncline and becomes thinner to the north. The lower part, Hiramatsu Formation, is mainly built up of arkosic sandstone and shale with an acid tuff and a coal layer near the top. The upper part called the Saragaizaka Formation is shallow marine and consists of micaceous and feldspathic sandstone and shale. It is characterized by several remarkably crowded of *Monotis* beds. At Chonomori and Kesennuma, *Monotis* succession is incomplete. Strata comparable to the Saragai Group are distributed in the Ofunato City where *Monotis ochotica* was discovered in the volcaniclastic strata below the Early Cretaceous Ofunato Group.

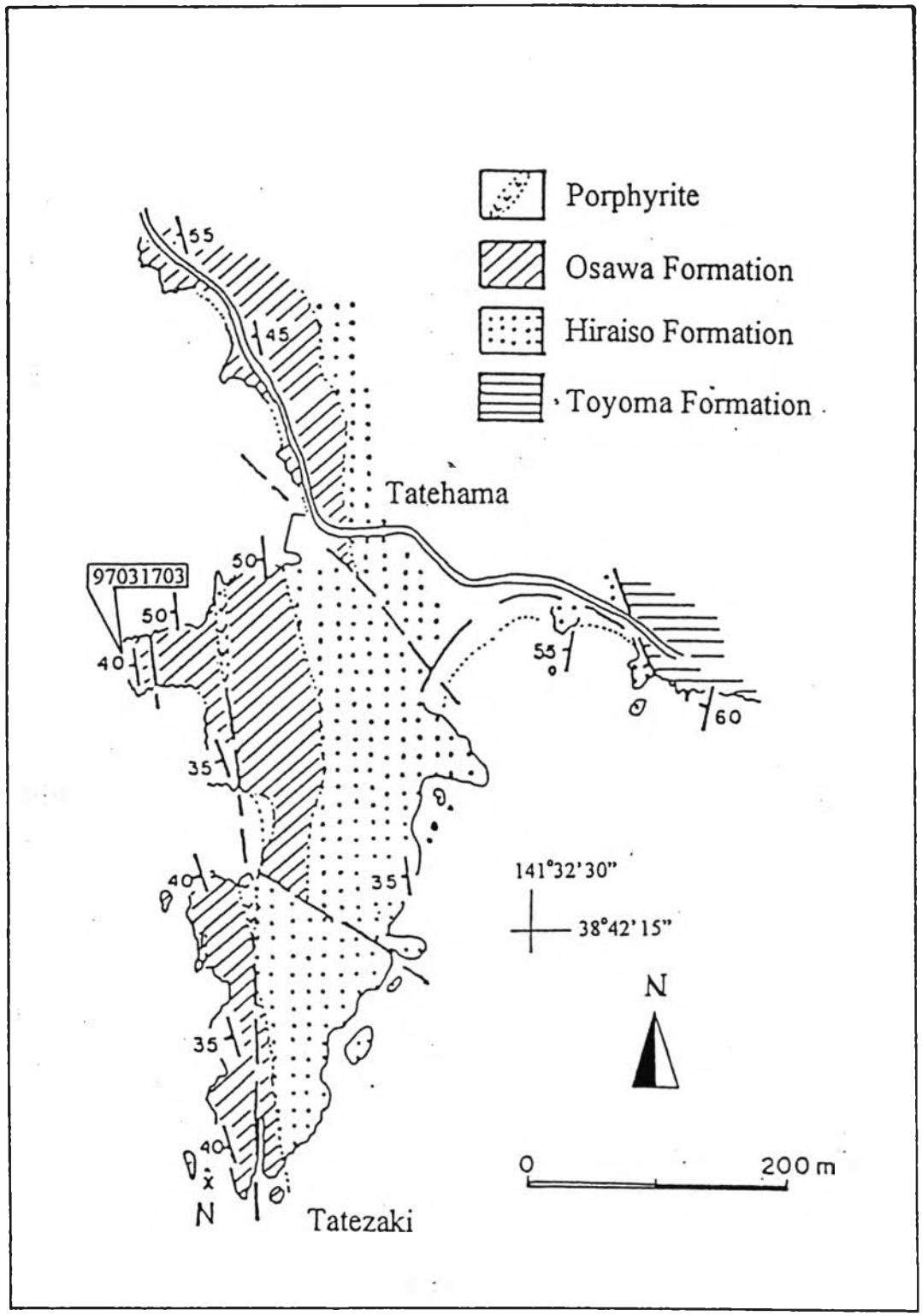


Figure 3.14 Geologic map around the Cape Tatezaki, Utatsu district (Mori *et al.*, 1992). Location where detrital chromian spinels were found is shown by the number of sandstone sample.

Figure 3.15 Thick-bedded fine-grained yellowish brown sandstone yielding fish fossil in Osawa Formation of Triassic Inai Group at the coast of Utatsu district.

Figure 3.16 Close-up of very fine-grained whitish gray sandstone strata of Triassic Osawa Formation in Inai Group near the coast of Utatsu district.

3.6 Jurassic

Jurassic shelf-facies formations, like those of Triassic, are distributed along the synclines in the coastal area of Miyamori prefecture. The Shizukawa and Hashiura Groups are found in three separated local areas, Shizukawa, Hashiura, and Mizunuma, of the western syncline, whereas somewhat thicker sediments corresponding to the Hashiura Group are exposed in the Karakuwa and Ojika local areas of the eastern syncline. Successions of Jurassic rocks in the Southern Kitakami area are depicted in Table 3.6.

The Shizukawa Group, 200 m thick, shows a sedimentary cycle. In the type locality (Shizukawa), it rests disconformably over the slightly eroded surface of the uppermost member of the Norian Saragai Group. Its basal part, Niranohama Formation, is subdivided into a lower blackish-water-bivalve bearing and an upper trigoniid bearing coarse-grained sandstone members. Detrital chromian spinels were detected in sandstones of this group by Takeuchi (1994). The exposures of sandstones in Shizukawa Group are shown in Figures 3.17 and 3.18. The upper part of the Niranohama Formation merges into the Hosoura Formation, which almost wholly consists of well-stratified marine sandy shale.

Along the eastern limb of the western synclinal belt, the Hashiura Group (600 m thick), rests disconformably on the Shizukawa Group, but it clearly overlaps the latter and commonly covers the Anisian Isatomae Formation of the Inai Group directly in the axial part and on the western limb. This group begins with the Aratozaki Formation, which is chiefly composed of massive sandstone. Its basal member yields bivalves and some small ammonites, which suggest a late Aalenian or earliest Bajocian age (Kobayashi and Mori, 1954). The upper member is made up of alternations of sandstone and shale, which seem to merge into the Arato Formation. The lower part of

Table 3.6 Successions of Jurassic sequences in the Southern Kitakami area

(Kimura *et al.*, 1991)

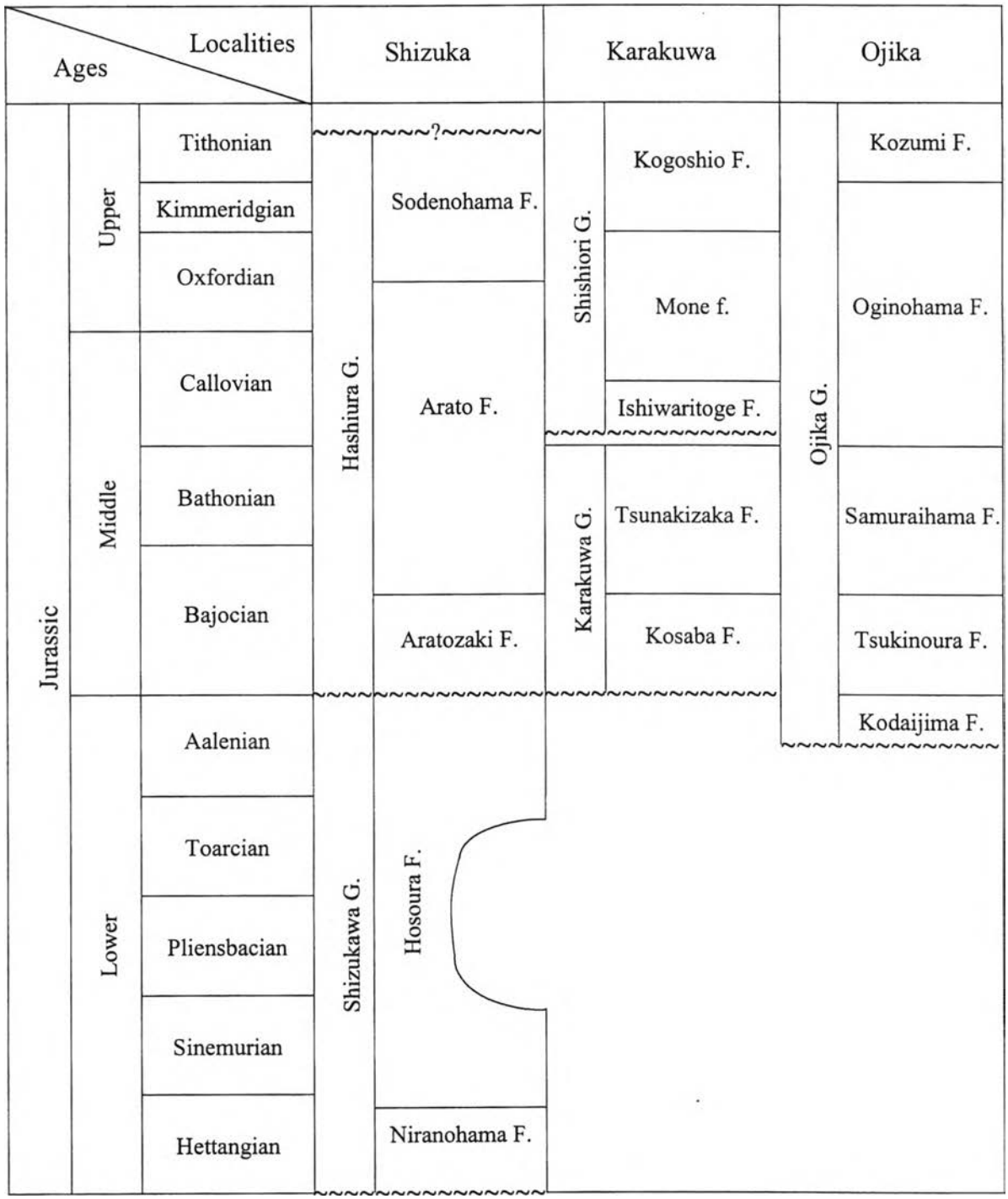


Figure 3.17 Bedded medium- to coarse-grained yellowish brown sandstones of Jurassic Shizukawa Group in Shizukawa district.

Figure 3.18 Intercalation of bedded very fine-grained whitish gray with coarse-grained yellowish brown sandstones in the Jurassic Shizukawa Group near the coast of Shizukawa district.

Arato Formation is partly sandy and contain fossils of Bajocian age, such as *Leptosphinctes* and *Oecotraustes*. The main agillaceous part of the Arato Formation is poor in fossils, but some spicies of *Kepplerites* are known in the Shizukawa and Mizunuma districts. The Sodenohama Formation, distributed locally in the Shizukawa district, has alternating sandstone and sandy shale layers. Similar successions of the Shizukawa and Hashiura Groups are observed in the Hashiura and Mizunuma districts, but a detailed stratigraphic division is difficult to make due to the rarer occurrence of the index fossils and strong deformation of the strata.

In the eastern syncline, no lower Jurassic strata exist. The strata that correspond to the Hashiura Group are represented by thick clastic sequences, called the Karakuwa and Shishiori Groups in the Karakuwa district and the Ojika Group in the Ojika peninsula. The Karakuwa Group begins with sandstone of the Kosaba Formation, which directly covers the Inai Group and bears the same species of *Trigonia* as the Aratozaki Formation. The overlying Tsunakizaka Formation is composed of black shale that contains Bajocian ammonites. The Shishiori Group, 1,000-1,400 m thick, commences with a thick conglomerate called Ishiwaritoge Formation, which is followed by an alternating layer of sandstone and plant-bearing shale. It constitutes the main part of the Mone Formation. The upper part of the Mone Formation and the overlying Kogoshio Formation are mostly marine on the basis of the appearance of *Myophorella (Haidaia)* and a layer of oolitic calcareous sandstone. Coarse-grained arkosic sandstone predominates in the main part of the Kogoshio Formation.

In Ojika peninsula, the Middle and Upper Jurassic are represented by the Ojika Group, more than 3,000 m thick, but the upper part must be Early Cretaceous. This group forms a syncline together with the Triassic Inai Group which constitutes the basement. Its Jurassic part is mainly thick sandstone, shale, and their alternation. In ascending order, it is subdivided into the Tsukinoura, Samuraihama, and Oginohama

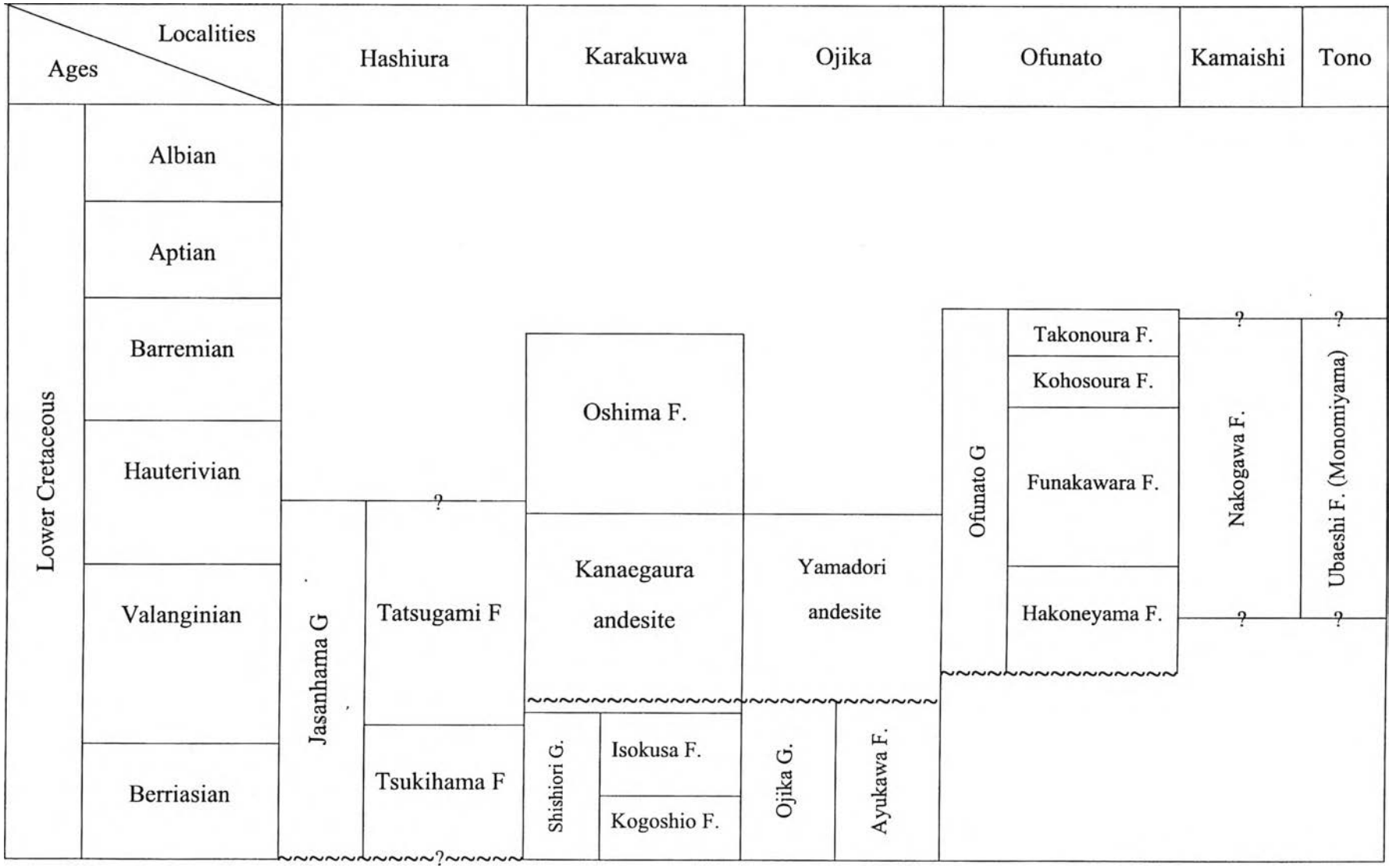
Formations. The strata have, in general, suffered from considerably strong cleavage folding, and their fossils are often almost homogeneously deformed, the major axis being subparallel to the folding axis. The Tsukinoura Formation, including the Kodaijima Formation, is sandy and partly conglomeratic and contains *Trigonia sumiyagura* in neritic sandstone and *Kobayashites* in paralic shale. The Samuraiham Formation, which is mostly black shale with generally strong slaty cleavage, yields *Otoites* and a few other Bajocian ammonites. The Oginihama Formation is principally composed of thick alternation of sandy and shaly members, which yield mostly marine plant fossils.

3.7 Cretaceous

The Early Cretaceous sediments in this area are marine or paralic and have been affected by cleavage folding together with the Jurassic and older rocks. Successions of Cretaceous rocks in the Southern Kitakami area are shown in Table 3.7.

The Jusanhama Formation, 300 m thick, in the Hashiura district covers the Hashiura Group disconformably and bears some plants and indigenous paralic bivales, but its exact age is still doubtful. In the Karakuwa (Oshima) district, marine Neocomian strata overlie the Middle-Late Jurassic Shishiori Group. The Isokusa Formation, represented by two small outcrops in the Oshima Island, near Kesennuma district, yields some marine bivalves common to the uppermost part of the Tithonian Kogoshio Formation. Although the stratigraphic relation is obscure, the Isokusa Formation seem to be overlain by Kanaegaura andesitic rocks and further by the Oshima Formation, 300 m thick, which is partly calcareous and bears *Crioceratites*, nerineids, corals, and bivalves. Similar andesitic rocks are distributed in the west of Kesennuma district. Near the point of the Ojika peninsula, the Ayukuwa Formation, more than 1,000 m thick, represents the uppermost division of the Ojika Group, and is

Table 3.7 Successions of Lower Cretaceous sequences in the Southern Kitakami area (Kimura *et al.*, 1991)



characterized by thick cross-bedded sandstone and plant-bearing shale. The Ayukawa is overlain by Yamadori andesitic rocks, which are correlated with the Kanaegaura of the Karakuwa district.

Unlike the preceding formations, the Ofunato Group (2,500 m thick) rests unconformably upon Permian strata. It bears brackish-water molluscs in its lower part and marine molluscs in its middle-upper part. Index fossils are rare in this group, but *Creoceratites* had been recorded from the middle part and *Holcodiscus* from the upper part. Fossiliferous strata comparable to this group, called the Nekogawa Formation, are found near the Kamaishi mine where paralic bivalves are known.

The Ubaishi (Monomiyama) Formation, west of Tono City, is an exceptional deposit in the Southern Kitakami area due to the fact that it yields non-marine bivalves (e.g., *Nagdongia* and *Pseudohyria*), which are shared with the Nagdong fauna of the Gyeongsang Group in South Korea (Tazawa *et al.*, 1979; Ogasawara, 1988).