Reconstruction of the Shallow-Water Limestone Sequence, in the Hikone Quarry, the North Part of the Suzuka Mountains, Central Japan

Takeshi YAMAGATA*

Abstract

I surveyed the Permian oceanic rocks in the Hikone quarry (Sumitomo Cement Co.), lying in the north part of the Suzuka Mountains, Shiga Prefecture, central Japan to declare stratigraphy and depositional environments of the Permian shallow-water limestone in the south part of the Mino terrane. The limestone sequence in the quarry are divided into lithologically different Lower Permian three members, which are composed of typically eight limestone rock-types. The rocks of the lower and middle members are attributed to deposits which accumulated on a carbonate bank, where lagoonal mud flats with low water-energies and sand bars and shoals with higher energies were included. Limestone-breccia of the upper member is assigned as limestone talus deposits in an upper slope of the carbonate bank.

I. Introduction

Numerous seamounts are distributed on the modern ocean floors. Approximately one thousand seamounts are reported in the western Pacific Ocean. Some of these modern seamounts are being collided to and subducted beneath forearc wedges of accretionary prisms in the modern trenches; the Japan Trench (Cadet *et al*., 1987; Lallemand and Le Pichon, 1987; Kobayashi *et al*., 1987; Yamazaki and Okamura, 1989), the Izu-Ogasawara Trench (Fryer and Smoot, 1985; Okamura *et al*., 1992), the New Hebrides Trench (Fisher, 1986; Collot and Fisher, 1989). These seamounts have been split and fractured by block faulting along outer slopes of trenches (Fryer and Smoot, 1985; Cadet *et al*., 1987). Breccias and blocks derived from seamounts are being deposited at the foot of fault-scarps and on the trench floors (Lallemand *et al*., 1989; Pautot *et al*., 1987). Some of the breccias and blocks have been accreted in the landward slope of the trench (*i.e*., the Daiichi-Kashima Seamount in the Japan Trench: Kobayashi *et al*., 1987). However, most parts of those seamounts have been totally subducted beneath forearc wedges, not having been detached from the oceanic floor nor obducted onto the forearc wedges. Only top parts of the seamounts are known to have been detached and incorporated into accretionary prisms of forearc wedges (Okamura, 1991). Magnetic anomalies and morphologic features indicate the presence of previously subducted seamounts beneath forearc wedges at the junction of the Japan and Kuril Trenches (Lallemand and Le Pichon, 1987; Yamazaki and Okamura, 1989), in the Nankai Trough (Okamura and Joshima, 1986; Yamazaki and Okamura, 1989), and in the New Hebrides Trench (Collot and Fisher, 1989).

On the other hand, the Mino terrane, the Jurassic accretionary prism in central Japan often includes huge masses of Permian oceanic rocks reconstructed as remnants of seamounts and the masses compose a part of a laterally discontinuous chain (Fig. 1C) traced from Hachiman (Wakita, 1984; Horibo, 1990), Funabuseyama (Kawai, 1964; Sano, 1988 a, b, 1989a, b), Uokaneyama (Yamamoto, 1985), Ibukiyama (Yamamoto, 1985), and Ryozensan (Miyamura *et al*., 1976) to Fujiwaradake (Murata, 1960; Harayama *et al*., 1989). Much of these huge masses are exposed as allochthonous thrust-sheets resting on terrigenous rocks. Therefore, the accretion model of modern seamounts can easily be applied to these accreted ancient seamounts. The shallow-water limestone of the Permian huge masses, especially the north part of the Mino terrane from

* Department of Natural Sciences, Komazawa University, Tokyo 154–8525, Japan.
e-mail: tyama@komazawa-u.ac.jp

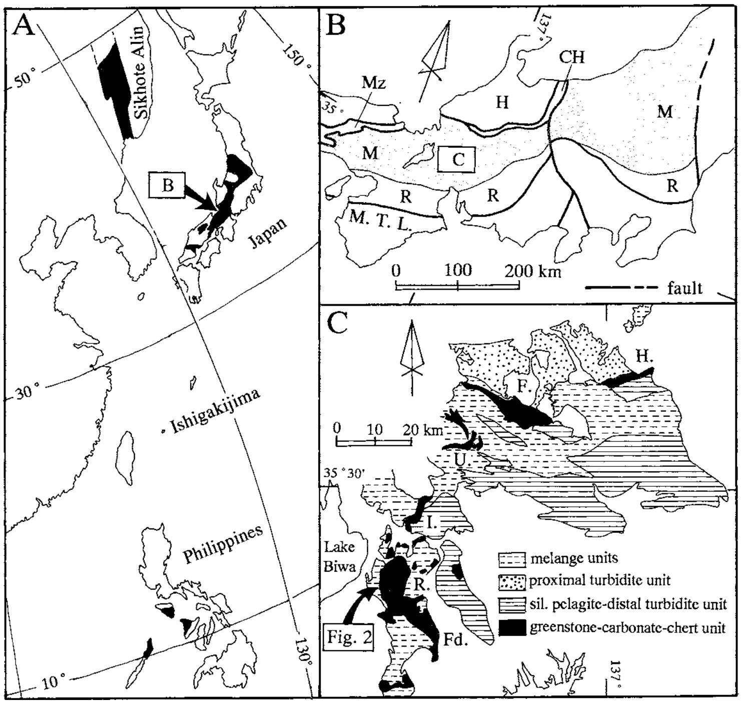

Figure 1. Index maps showing geographic (A), tectonic (B), and tectonostratigraphic (C) of the Mino terrane

CH: Circum-Hida Tectonic Zone, H: Hida terrane, M: Mino terrane, Mz: Maizuru terrane, R: Ryoke metamorphic terrane, M.T.L.: Medium Tectonic Line. H: Hachiman, F: Funabuseyama, U: Uokaneyama, I: Ibukiyama, R: Ryozen, Fd.: Fujiwaradake. The Hikone quarry is located in the west area of this map. Locality is shown in Figure 1B.

Hachiman to Funabuseyama, were particularly examined. The evidence and data on the base of paleomagnetism (Hattori, 1982; Hattori and Hirooka, 1977, 1979) and limestone-stratigraphy (Sano, 1988a; Horibo, 1990) also show that the Permian oceanic rocks of the north part of the Mino terrane originated in the seamounts and the surrounding sedimentary rocks formed in the low latitude open ocean. By contrast, in the south part of the Mino terrane, the stratigrahy and depositional environments of the Permian oceanic rocks mostly have not just yet been surveyed.

To better understand stratigraphy and depositional environments of the Permain oceanic rocks, especially shallow-water limestone in the south part of the Mino terrane, I studied the Permian limestone in the Hikone quarry (Sumitomo Cement Co.), lying in the north part of the Suzuka Mountains, Shiga Prefecture, central Japan. I surveyed the Permian oceanic rocks and collected about 1200 rock samples in the area of a meter in the field. I made thin-sections of all the samples and observed them under the microscope.

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II. Geologic Setting

1. Geologic outline of the Mino terrane

Mizutani and Hattori (1983) have defined the Mino terrane as the Mesozoic terrane composed of a heterogeneous assemblage of unmetamorphosed, upper Paleozoic and Mesozoic rocks in the continental side of southwest Japan. The northern correlative of the Mino terrane is described in Sikhote-Alin (Nadanhada-Western Sikhote-Alin: Kojima, 1989). Southern correlatives are found in the Philippines (North Palawan Block: Isozaki *et al.*, 1988; Faure and Ishida, 1990) and Ishigakijima Island (Isozaki *et al.*, 1989). The Mino terrane and its northern and southern correlatives form a belt of Jurassic accretionary rocks fringing the eastern continental margin of Asia (Figure 1A).

In central Japan where the Mino terrane rocks best crop out, the northern margin of the Mino terrane is tectonically bounded by the Circum-Hida Tectonic Zone, and the Maizuru terrane (Figure 1B). In the south of the Mino terrane, the rocks gradually grade into the Ryoke metamorphic terrane.

A great deal of recent radiolarian biostratigraphic works (Wakita, 1988; Otsuka, 1988) as well as geological studies have completely revised the tectonostratigraphy and age of the Mino terrane rocks, much of which was previously believed to be Carboniferous and Permian. According to the tectonostratigraphy recently proposed by Sano *et al*. (1992), the Mesozoic and Paleozoic rocks of the Mino terrane can be grouped into four units (Figure 1C); (1) Permian greenstone-carbonate-chert unit, (2) Lower Triassic to lowest Cretaceous siliceous pelagitc-distal turbidite unit, (3) Middle Jurassic proximal turbidite unit, and (4) upper Lower Jurassic to lowest Cretaceous melange unit. Sano *et al*. (1992) interpret these four units to be (1) sediments on and around a seamount in an open-ocean realm, (2) sediments accumulated in a pelagic realm to trench floor setting, in ascending order, (3) sediments deposited in a trench-slope basin, and (4) submarine slide deposits on a trench floor, respectively. Geochemical investigation shows that the volcanism setting of basaltic rocks of the greenstone-carbonate-chert unit was most likely a spreading axis-centered oceanic plateau or ridge (Jones *et al*., 1993).

All these rocks form southerly-vergent, imbricated, complexly stacked structural wedges and show a southward younging polarity (Sano *et al*., 1992; Wakita, 1988; Otsuka, 1988; Yamagata, 1989). Moreover, paleomagnetic examinations of the Mesozoic pelagic sediments and Permian basaltic rocks (Hattori and Hirooka, 1977, 1979; Shibuta and Sasajima, 1980; Hattori, 1982) have revealed that these rocks accumulated in low-latitude areas far away to the south of the present position. All lines of evidence indicate that the sedimentary complex of the Mino terrane was formed by collision of the Permian to Jurassic oceanic rocks and their offscraping accretion together with Jurassic to earliest Cretaceous terrigenous sediments in a trench area (Sano *et al*., 1992).

II. Previous Works and Geologic Framework in North Part of the Suzuka Mountains

Miyamura *et al*. (1976) were the first to examine the stratigraphy of rocks of the Mino terrane in the Suzuka Mountains and have divided the Mino terrane rocks into the Ikuridani, Hikone, and Kitasuzuka Groups. The Ikuridani Group is composed of sandstone, black mudstone, and chert intercalating limestone lens. The Hikone Group was lithologically subdivided into the lower Mitigadani and upper Maihara Formations. The Mitigadani Formation is composed mainly of black mudstone containing lenticular beds of chert, and the Maihara Formation comprises black mudstone and chert with a small amount of sandstone. The Kitasuzuka Group was subdivided into the lower Ojigahata and upper Ryozensan Limestone Formations. The Ojigahata Formation is composed of predominant chert which intercalates black mudstone, and the Ryozensan Limestone Formation consists mainly of limestone and basaltic rocks with a small amount of sandstone and black mudstone. The three groups were presumed to be correlated with the Lower Permian on the basis of fusuline fossils yielded from limestone.

However, radiolarian and conodont biostratigraphies revealed that the Ojigahata Formation included both Jurassic (Kurimoto and Kuwahara, 1991) and Permian chert (Suetsugu, 1981) and the Hikone and Ikuridani Groups corresponded to the Jurassic (Okimura *et al*., 1986: Harayama *et al*., 1989). Moreover, Yamagata (1990, 1992, 1993) showed that the Hikone and Ikuridani Groups were early Late Jurassic olistostromes, which comprise black mudstone containing blocks of Jurassic siliceous rocks and sandstone, and the black mudstone of the Kitasuzuka Group was equivalent to the olistostromes. Yamagata (2000) clarified that the Kitasuzuaka Group have been formed by debris avalanche-related intermixing of disrupted blocks and rocks-pieces of limestone, chert, and basal and finer-pulverized basaltic particles (Figure 2). The study area, the Hikone quarry, is located in huge rock-masses of limestone (Figure 2).

III. Stratigraphy of the Limestone in the Hikone Quarry

The Hikone quarry (Figure 3) was developed

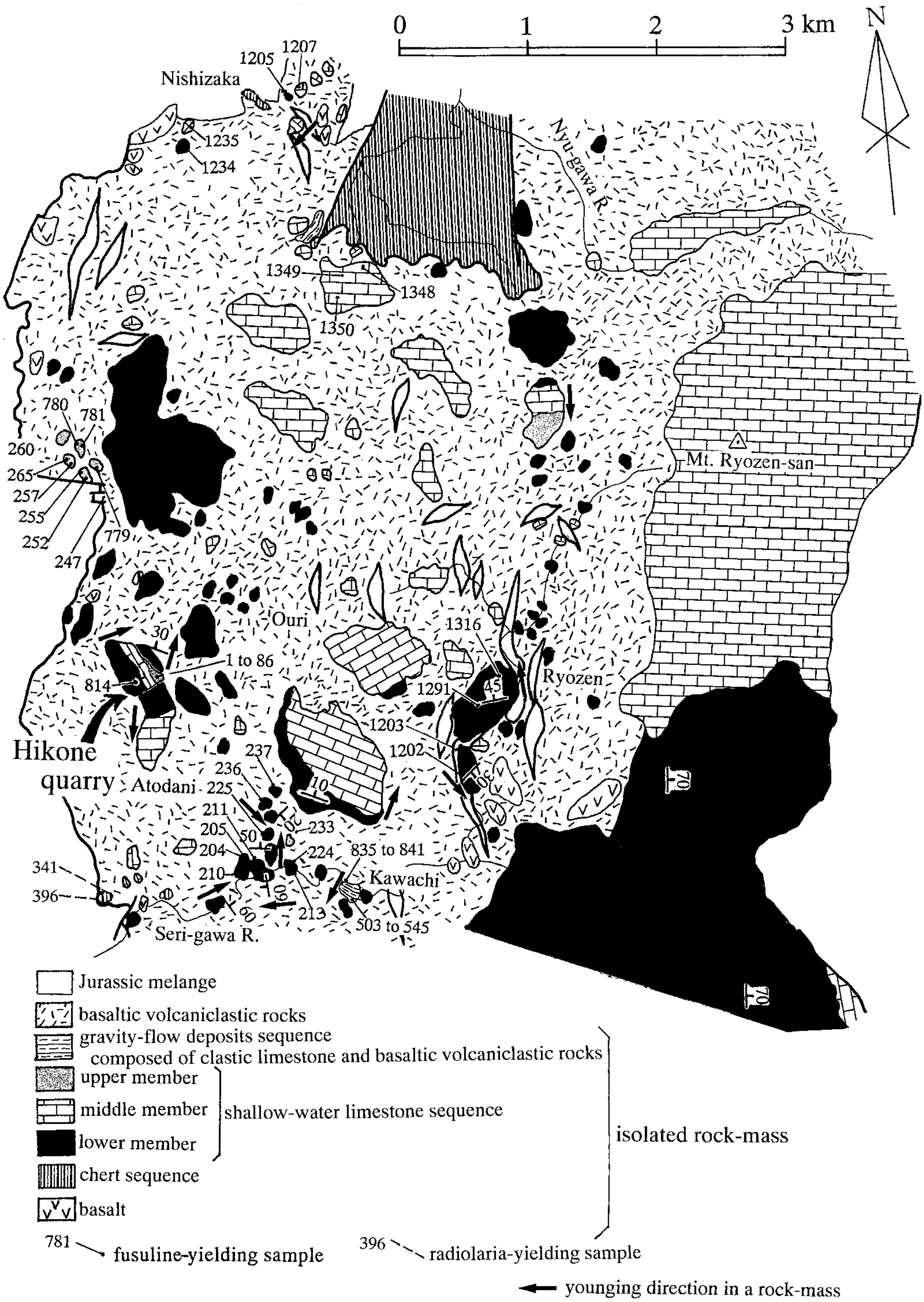

Figure 2. Map showing the distribution of major, mappable-sized and isolated rock-masses of the Permian oceanic rocks
Modified from Yamagata (2000)

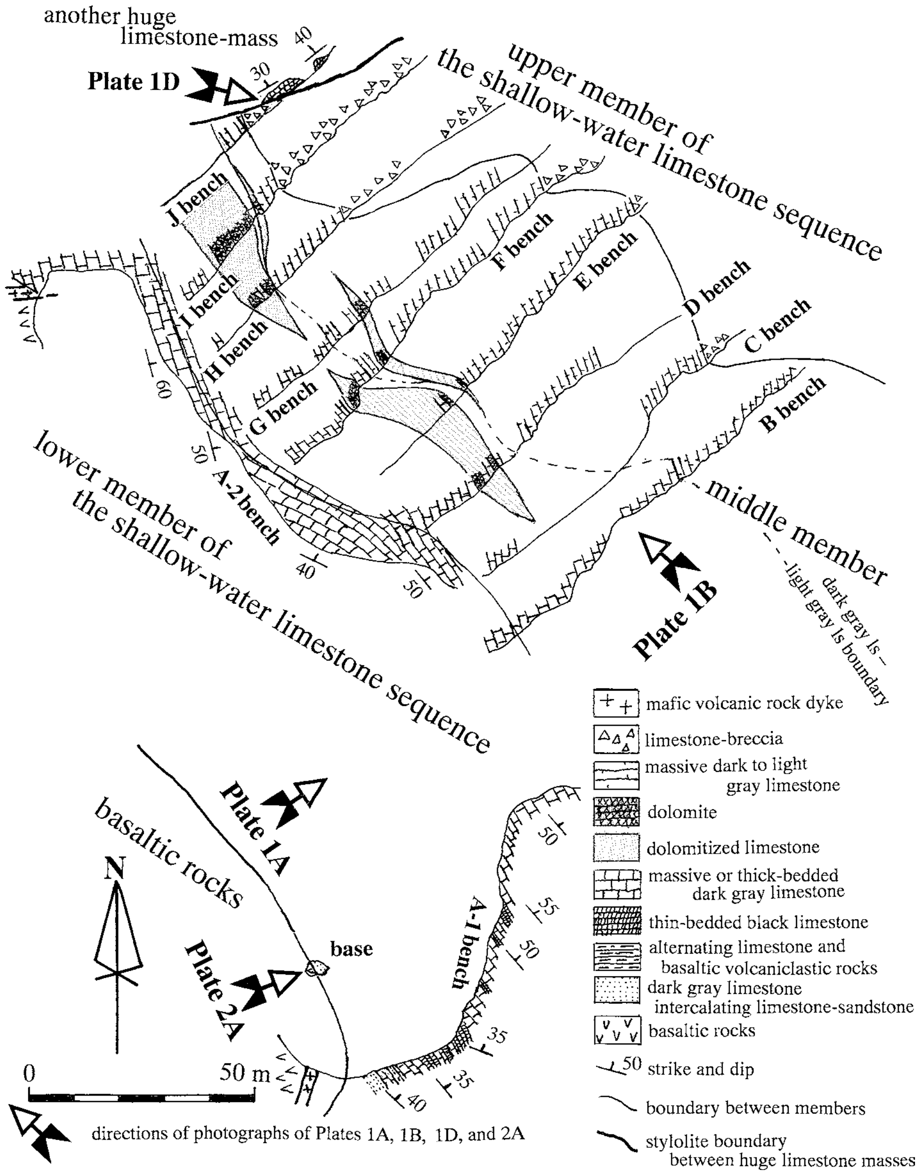

Figure 3. Detailed map in the Hikone quarry
In this quarry, almost all of the shallow-water limestone sequence is observed.

by Sumitomo Cement Co. and now is not being quarried out. The limestone huge mass has been cut as one big bench (approximately 50 m high: bench A-1 and A-2 of Plate 1A) and nine small benches (approximately 3 m high: bench b–j of Plate 1B). In the big bench, the lower and middle members of the shallow-water limestone sequence (Figure 4 and Plate 1A) outcrops and the middle and upper members of the sequence (Figure 4 and Plate 1B) are distributed on the small benches. The studied block of the limestone is in a stylolite contact on an another rock-mass of limestone (Plate ID).

The shallow-water limestone sequence consists mostly of fossiliferous limestones showing various rock-types and limestone-breccia, and is accompanied by basaltic volcaniclastics at the bottom (Figure 5 and Plate 2A). The reconstructed sequence of the shallow-marine limestone succession is approximately 230 m thick and is lithologically subdivided into the three members.

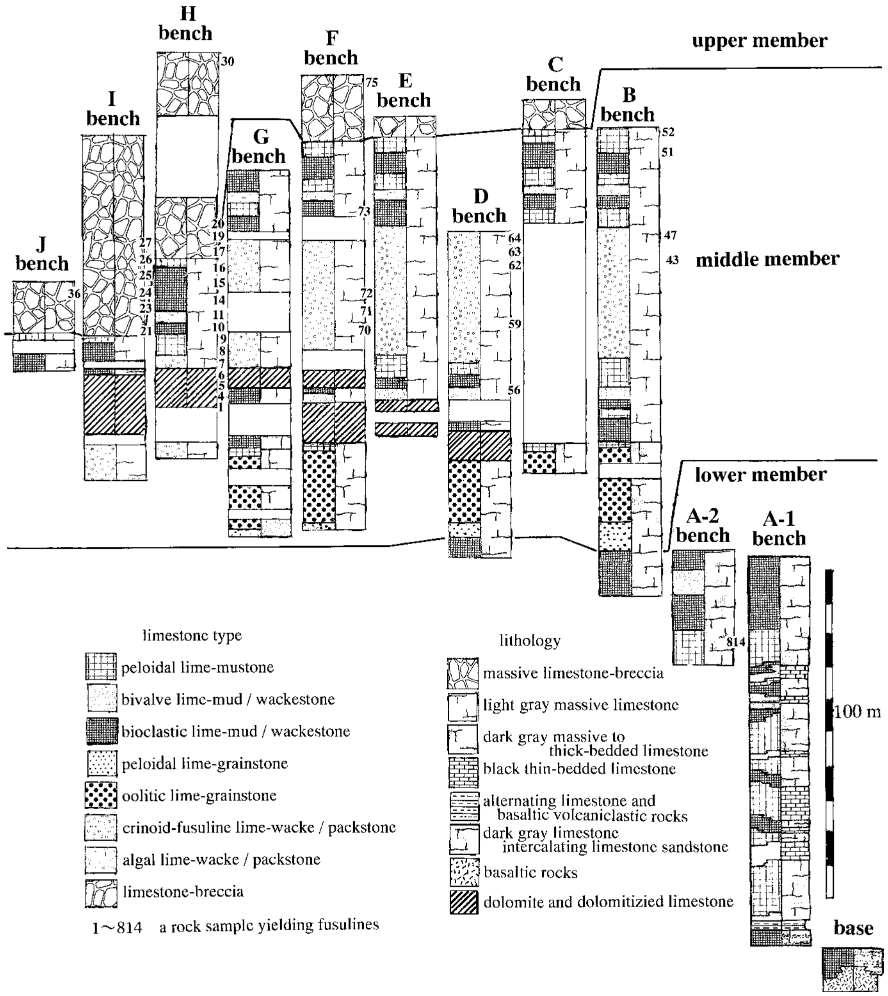

Figure 4. Columnar sections obtained on benches in the Hikone quarry
Localities of the benches are shown in Figure 2.

1. Lithostratigraphy

(1) Lower member (approximately 100 m thick)

The limestones of the lower member are dark gray to black. The dark gray limestones are structureless to thick-bedded, and the black limestone is thin- to thick-bedded (Plate 2B). The beds range in thickness from several centimeters to a few meters. The distinctly thin-bedded black limestones are carbonaceous and have black calcareous, carbonaceous matter-rich claystone partings of less than several centimeters thickness. The bedded limestones are often intraformationally folded. At the base of the succession, the dark gray limestone is thinly interbedded with dark green basaltic volcaniclastic sandstone composed of basalt detritus of silt- to sand-size (Plate 2C). Limestone-sandstone which contains a few grains of scoria and dolomite occurs intercalated in the lower part of the lower member.

The most characteristic particles of the lower member are peloids, thick-shell bivalves, and cyanobacterias. Subordinate are the small foraminifers, gastropods, brachiopods, crinoids, fusulines, ostracods, Tubiphytes, green algae, red algae, echinoids, corals, and calcispheres. In addition to these organic debris, a large amount of algal peloids is contained in the matrix.

Most of the limestones of the member are described as lime-wacke/mudstone. A lesser amount of lime-packstone is in the upper part.

(2) Middle member (approximately 100 m thick)

The middle member is composed of massive

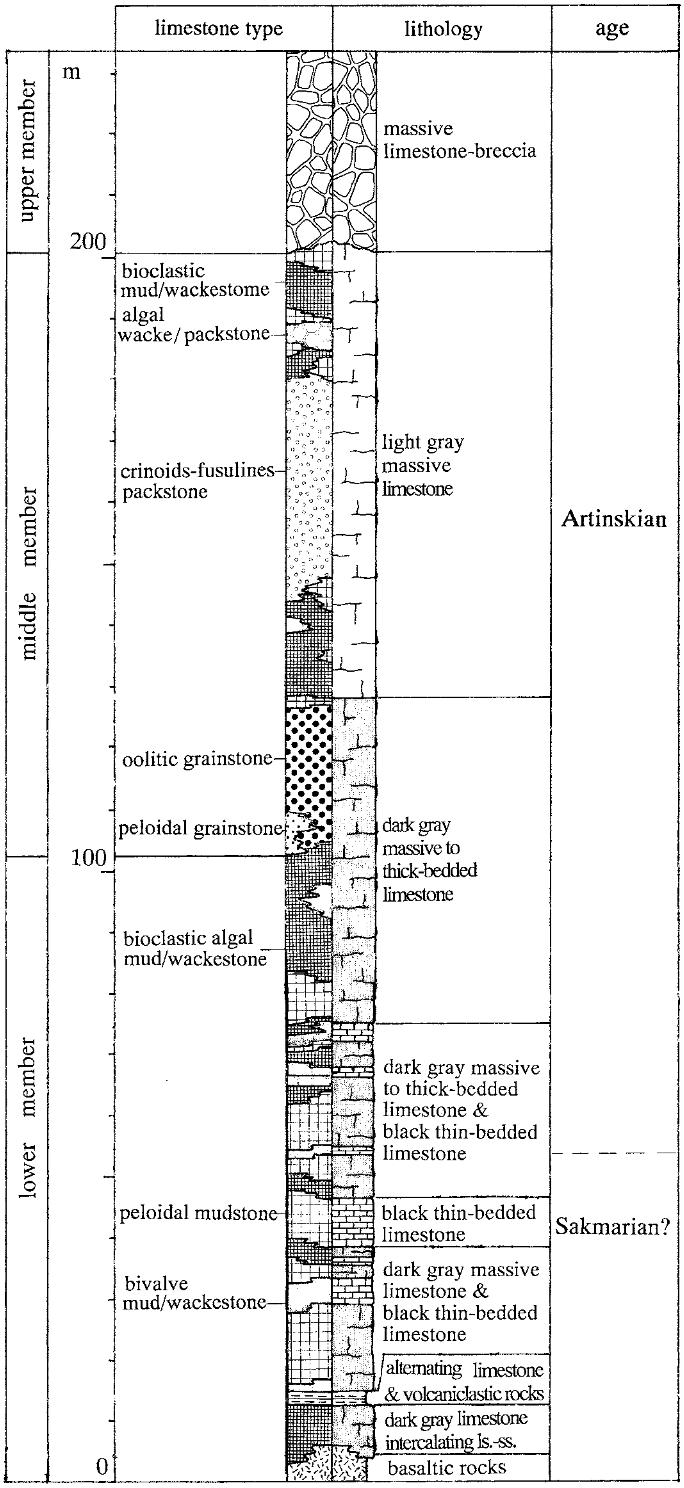

Figure 5. Composite columnar section showing the lithostratigraphy and age of the Permian shallow-water limestone sequence.
Modified from Yamagata (2000)

limestone (Plate 3A). The limestones of the lower and middle parts of the member are dark gray, and those of the upper part are light gray to gray. The limestones of the middle part are dolomitized (Plate 3B).

The limestones of the lower part of the member are characterized by a large amount of ooids and legal peloids of cyanobacterias including Girvanella and the subordinate smaller foraminifers, and Tubiphytes. All the limestones of the lower part are grainstone with sparry calcite cements.

The middle part of the member is dominated by bioclastic algal wackestone. All of the limestones of the middle part are dolomitized to varying degrees and recrystallized. The primary fabrics of the limestones are at places obliterated by intense, severe dolomitization. The limestones of the middle member contain fusulines, crinoids, cyanobacterias, and the smaller foraminifers.

The limestones of the upper part of the member are mainly described as packstone and wackestone. The limestones are characterized by fusulines and crinoids. The smaller foraminifers, cyanobacterias, Tubiphytes, bryozoas, red algae, bivalves, and algal peloids are subordinate. Much of the packstone has a lime-mud matrix and spar-filled primary voids.

(3) Upper member (up to 30 m thick)

The upper member is composed of limestone-breccia (Plates 3A and Plate 6C). The limestone-breccia of the upper member conformably overlies the middle member. The boundaries between these members are generally indistinct and uneven.

The limestone-breccia is massive and consists mainly of a large amount of limestone clasts of various rock-types and a small amount of dolomite detritus with very rare or no lime-mudstone matrix.

The limestone clasts are unsorted, ranging in size from a few millimeters to several meters, and essentially angular-shaped. The lithoclasts are supported by one another and completely disorganized without any oriented fabrics.

2. Age

The shallow-water limestone was dated by means of the fusuline biostratigraphy. From the bioclastic limestones of the study area, 17 fusuline species belonging to 9 genera were yielded (Table 1). The detail biostatigraphic data is shown in Yamagata (2000).

From the lower member in the Hikone quarry, no fusulines available for the precise age determination were yielded. However, a limestone sequence extremely lithologically similar to the lower member yieled fusulines including *Minojapanella* sp., *Pseudoschwagerina*? sp., *Pseudofusulina* sp., and *Biwaella* sp, and so the lower member in the Hikone quarry may indicate that the lower member is correlated to the Sakmarian.

The middle member and all the limestone clasts of the upper member are referred to as the *Pseudofusulina vulgaris* Zone indicative of the lower to middle Artinskian. *Pseudofusulina exigua* (SCHELLWIEN), *Pseudofusulina fusiformis* (SCHELLWIEN), *Pseudofusulina lutugini* (SCHELLWIEN), and *Pseudofusulina vulgaris* (SCHELLWIEN) are characteristic of the fusuline fauna. Noteworthy is that the limestone clasts yield no fusulines showing different ages from the Artinskian.

3. Limestone-types

The limestone-types of the shallow-water limestone in the Hikone quarry are grouped into eight major types with fabrics and dominant grain-types: (1) peloidal lime-mudstone, (2) bivalve lime-mud/wackestone, (3) bioclastic lime-mud/wackestone, (4) peloidal lime-grainstone, (5) oolitic lime-grainstone, (6) crinoid-fusuline lime-wacke/packstone, (7) algal lime-wackestone, (8) limestone-breccia. The minor varieties occur, including algal lime-packstone in the lower member, which contains abundant algal oncoids formed by encrustation of cyanobacterias.

(1) Peloidal lime-mudstone

The limestone of this type is characterized by dominance of the well-sorted peloidal lime-mud matrix and scarcity of coarse skeletal debris (Plate 4A). A small amount of bivalves, gastropods, brachiopods, ostracods, crinoids, calcispheres, and cyanobacterias is in places scattered. All these skeletal debris are supported by the matrix.

This type of limestone is common in the lower member and is found also in the middle member.

(2) Bivalve lime-mud/wackestone

The limestone of this type consists of abundant thick- and thin-shelled bivalves (Plate 4B) and their fragments with a small amount of green algae, cyanobacterias, ostracods, crinoids, calcispheres, the smaller foraminifers, Tubiphytes, gastropods, and brachiopods. All the skeletal particles are supported by the matrix composed of a mixture of lime-mud and silt-sized bioclastic

Table 1. List of fusulines yielding from the shallow-water limestones in the Hikone quarry

upper member									75	17	19	20	21,27	23	24	25	26	30	36	
middle member	1,4,52,56, 59,63,64, 71	5,51,70	6	7	8,15,72	9,10	11	14	16,43,62, 86		73									47
lower member										814										
Acervoschwagerina sp.								+												
Biwaella sp.												+						+		+
Mesoschubertella sp.																			+	
Nankinella sp.																		+		
Paraschwagerina sp.									+		+									
Pseudofusulina ambigua (DEPRAT)			+																	
P. fusiformis (SCHELLWIEN)					+	+														
p. globosa (SCHELLWIEN)																+				
P. kraffti (SCHELLWIEN)				+																
P. lutugini (SCHELLWIEN)		+					+							+				+		+
P. tschernyschewi (SCHELLWIEN)			+									+								
P. vulgaris (SCHELLWIEN)													+	+	+		+	+		
P. sp.	+										+									
Pseudoschwagerina sp.										+										
Schubertella sp.						+	+					+		+	+		+	+		
Schwagerina sp.															+					
S. krotowi (SCHELLWIEN)																			+	

grains. Bivalve shells and crinoid oscicles are in places encrusted by cyanobacterias.

This type is common in the lower member and is found also in the middle member. Some of the limestone clasts of the upper member comprise this type of limestone.

(3) Bioclastic lime-mud/wackestone

The limestone of this type contains diverse skeletal debris, including the smaller foraminifers, calcispheres, bivalves, gastropods, brachiopods, echinoids, ostracods, crinoids, fusulines, cyanobacterias, red algae, *Tubiphytes obscurus* MASOLV, and algal oncoids (Plates 4C, 4D, and 5A). These organic debris are supported by the poorly sorted lime-mud matrix with silt- to sand-sized bioclasts and peloids.

The cyanobacterias and Tubiphytes occur as algal tissues covering skeletal particles and micritic layers of oncoids. Algal-encrusted bioclastic particles are often micritized. Red algae are characterized by the reticulate structure formed by thin micrite walls separating small cells, and holes filled with sparite (Plates 4C, D).

The limestone of this type is common in the lower and middle members and also occurs as the lithoclasts in the limestone-breccia of the upper member.

(4) Peloidal lime-grainstone

Characteristic of this type is a considerable amount of peloids contained together with a small amount of bioclasts (Plates 5B). Skeletal debris include cyanobacterias, crinoids, calcispheres, the smaller foraminifers, and Tubiphytes. The peloids are very well sorted and medium sand-sized. Most of them are algal peloids originated from girvanellid cyanobacterias. All skeletal grains are filled with sparry calcite cement.

The limestone of this type is limited to the bottom of the middle member.

(5) Oolitic lime-grainstone

Most grains of this type comprise ooids (Plate 5C). Fragments of crinoids and bivalves with a small amount of fusulines and ostracods are identified as nuclei of ooids. The ooids are well sorted, 0.8 to 1.0 mm in diameter and have regular concentric micritic laminae coating the nucleus. The ooids are supported by each other and cemented by the spar.

The oolitic lime-grainstone occurs in restricted form in the lower part of the middle member.

(6) Algae-crinoid-fusuline lime-wacke/packstone

Essential skeletal debris of this type are fusulines and crinoids (Plate 5D). A large amount of minute tubes, which is supposed to be calcareous algae, are contained (Plate 5D). Associated with these biogenic particles, a small amount of cyanobacterias, red algae including Parachaetetes, green algae, the smaller foraminifers, *Tubiphytes obscurus* MASOLVE, and brachiopods are contained. The crinoids and brachiopod shells are encrusted and micritized by cyanobacterias. All the skeletal grains are densely packed and supported by one another and are in places randomly embedded in and supported by a matrix. The matrix is composed of poorly sorted lime-mud with some fine-grained bioclasts.

The limestone of this type is common in the middle member and occurs as lithoclasts of limestone-breccia of the upper member.

(7) Algal lime-wackestone

Accompanied by a small amount of fusulines, the smaller foraminifers, crinoids, Tubiphytes, calcispheres, ostracods, bivalves, and gastropods, short, tube-shaped cyanobacterias are the essential skeletal component of this type (Plate 6A). Cyanobacterias also occur as algal envelopes (Plate 6B). Most of the skeletal debris are supported by a lime-mud matrix and partly cemented by sparite.

The limestone of this type is in the upper part of the middle member and occurs as lithoclasts of limestone-breccia in the upper member.

(8) Limestone-breccia

The limestone-breccia contains abundant limestone clasts with a small amount of dolomite detritus and skeletal debris (Plate 6C). The limestone clasts are varying in size from a few millimeters to several meters, and angular-shaped. The rock-types of the limestone clasts are dominated by fusuline-crinoid lime-packstone and fusuline-peloidal lime-grainstone and include subordinate bioclastic lime-wackestone and algal bindstone. Almost all the limestone clasts are closely similar to the shallow-marine limestones of the middle member except for fusuline-peloidal lime-grainstone and algal bindstone.

Fusuline-peloidal lime-grainstone clast is characterized by abundant peloidal particles and fusulines (Plates 6D and 7A). Subordinate are the smaller foraminifers, cyanobacterias, green algae including Gyroporella and Pseudogyroporella, bivalves, gastropods, and crinoids. Most of the fusulines and crinoids are coated by thin algal micrite (Plate 7A). The type locally contains a small amount of intraclasts composed of lime-mudstone. All these particles are supported by one other and cemented by the sparite. Algal bindstone clast comprises thinly laminated layers of cyanobacterias (Plate 7B) and Archaeodiscpoleum with primary open spaces (Plates 7C and 7B). A large amount of skeletal debris including fusulines, the smaller foraminifers, bivalves, gastropods, calcispheres, Tubiphytes, and green algae is embedded within the algal layers. The open spaces within the algal mats are filled by sparry calcite.

The matrix of the limestone-breccia is composed of well-sorted lime-mud and mixture of lime-mud/silt and fine-grained bioclastic debris including fusulines, crinoids and algae. The lime-mud matrix also contains dolomite detritus, which are well-sorted, anhedral, and medium sand-sized. In case the matrix is absent, the lithoclasts are in stylolitic-sutured contact with one another (Plate 6C).

The limestone-breccia occurs only in the upper member of the shallow-marine limestone succession.

IV. Reconstruction of Depositional Setting of the Shallow-Water Limestone in the Hikone Quarry

The microscopic examination as well as the field observation indicates that no coarse terrigenous clastic grains are contained in the Permian limestone in the Hikone quarry. It is not that terrigenous rocks laterally and vertically pass into the Permian oceanic-rocks sequences. The total lack of coarse terrigenous clastic materials in the Permian sequences points to their accumulation in an open-ocean realm far beyond an input of coarse land-derived materials.

The Permian oceanic rocks of the Suzuka unit were subdivided into the four successions characterized by basaltic rocks, shallow-marine limestone, allochthonous limestone, and chert, respectively. The age of the basaltic rock succession though not dated, is best referable to the Early

Permian, for related basaltic rocks occur in the middle Lower Permian part of the shallow-marine limestone sequence.

The shallow-marine limestone sequence is similar in lithostratigraphy to the Funabuseyama and Amanokawara Formations in the Funabuseyama area (Sano, 1988a), Horikoshitoge and Akuda Formations in the Hachiman area (Horibo, 1990), and Nabeyama Formation in the Kuzuu area (Kobayashi, 1979). All of these rock-units are exposed as large-scaled masses set in the Mino terrane and its equivalent. In spite of the fact that the shallow-marine limestone succession differs in age from these rock-units, the lithologic affinity implies their similarity in the depositional setting.

The lithostratigraphy of the Funabuseyama, Horikoshitoge, and Nabeyama Formations is summarized as follows; well bedded, organic matter-rich lime-wackestone and packstone in the lower and massive to thick-bedded, partly dolomitized lime-packstone and grainstone in the upper. All these bioclastic limestones are rich in diverse shallow-marine skeletal debris. According to the facies interpretation by Sano (1988a) and Horibo (1990), the lower and upper units are referred to sediments in quiet, poorly water-circulated, stagnant, lagoonal mud flats and sediments in sand bars to shoals and lagoonal mud flats with a higher water-energy, all sitting on a carbonate bank at shallow water-depth, respectively. The lithostratigraphy of these successions is interpreted to represent an environmental change on shallow-marine carbonate banks. The environmental change is best expressed as an upward-increase of the water energy on carbonate banks upon a seamount.

The lithostratigraphy of the lower and middle members of the Suzuka shallow-marine limestone succession is comparable with that of the entire successions of Funabuseyama, Horikoshitoge, and Nabeyama Formations. The lower and middle members of the Suzuka shallow-marine limestone succession comprise bedded, carbonaceous lime-mudstone and wackestone rich in mollusks and algae and massive packstone and grainstone dominated by fusulines, crinoids, and algae and characterized by oolitic grains. The similarity of the Suzuka shallow-marine limestone succession in the lithostratigraphy to the Funabuseyama, Horikoshitoge, and Nabeyama Formations implies the similar trend of the environmental change. An increase in the water energy going upsection is considered to be the trend of the environmental change common throughout the Permian shallow-marine carbonate succession having a bank-top of the Mino terrane.

The rock-associations of the Amanokawara and Akuda Formations are characterized by talus deposits of limestone-breccia. Clasts of the limestone-breccia are polymictic, comprising diverse types of shallow-marine limestone. Sano (1989a) and Horibo (1990) interpreted the Amanokawara and Akuda Formations to be sediments in a marginal terrace to upper slope of a carbonate bank on a seamount, respectively.

Lithologically comparable with the Amanokawara and Akuda Formations is the upper member of the Suzuka shallow-marine limestone succession. Its major component is limestone-breccia comprising polymictic limestone-clasts of diverse types of shallow-marine limestone.

With an emphasis upon the lithologic affinity to the previously described rock-units of the Mino terrane, the lithostratigraphic and microscopic examinations lead the author to a facies interpretation of the Suzuka shallow-marine limestone succession. The rocks of its lower and middle members are assigned to deposits which accumulated on a carbonate bank, where lagoonal mud flats with low water-energies and sand bars and shoals with higher energies were included. Limestone-breccia of the upper member is referred to as limestone talus deposits in an upper slope of the carbonate bank.

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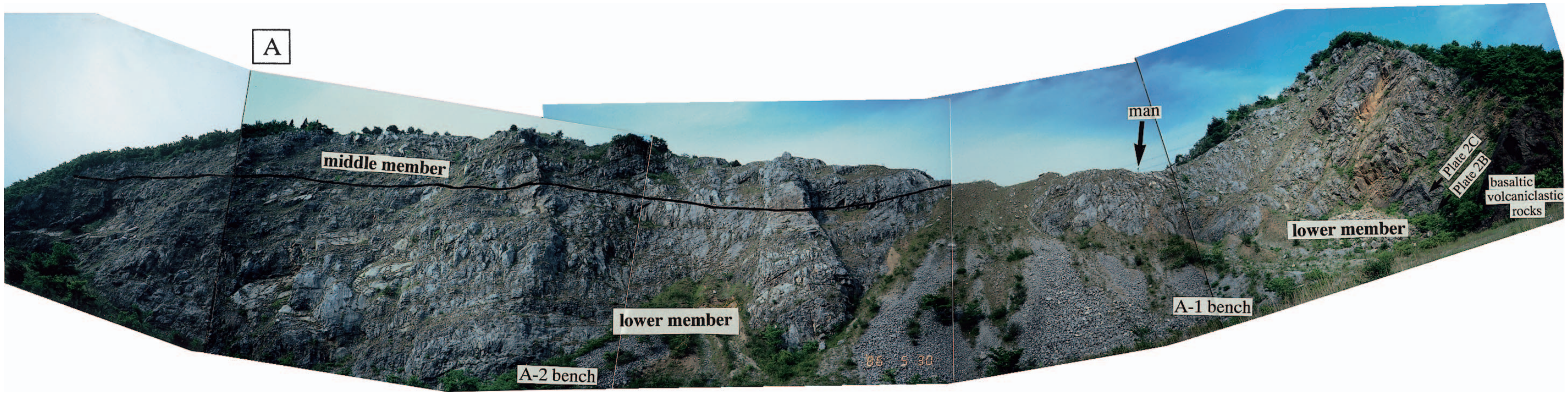

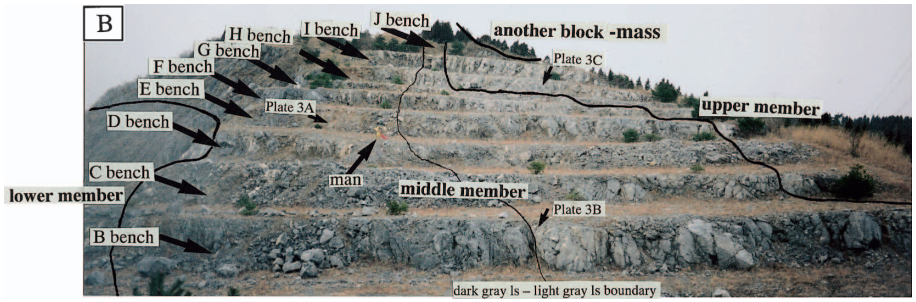

Plate 1. Photographs of the Hikone quarry (Sumitomo Cement Co.)
Locality of the Hikone quarry is shown in Figure 2.
A. A1 and A2 benches (about 50 m high) composed of the lower member of the shallow-water limestone sequence. Locality is shown in Figure 3.
B. Nine small benches (about 3 m high each other) from B bench to J bench. The rocks of the middle and upper member of the shallow-water limestone sequence are distributed in these benches. Locality is shown in Figure 3.

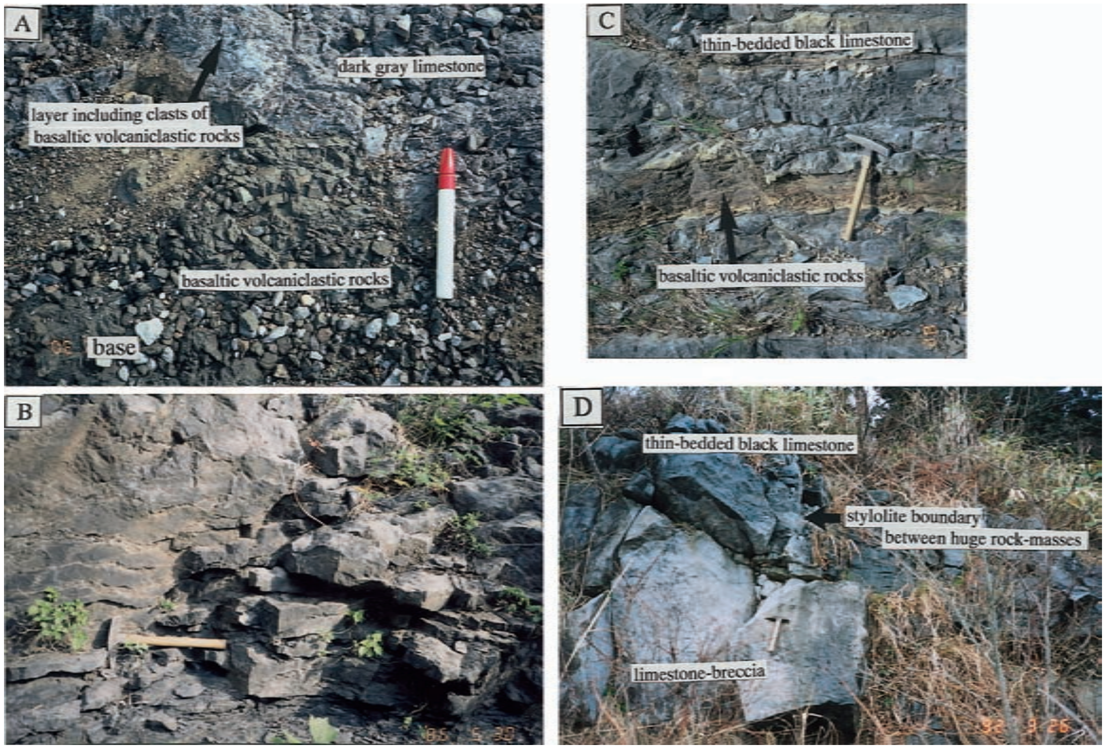

Plate 2. Outcrop views of the lower member of the shallow-water limestone sequence in the Hikone quarry

A. The dark gray limestones conformity overlying on the basaltic volcaniclastic rocks. The limestones at the boundary intercalate the layers composed of clasts of basaltic volcaniclastic rocks. Locality is shown in Figure 3.

B. The black bedded limestones of the lower member of the shallow-water limestone sequence. Locality is shown in Plate 1A.

C. The black bedded limestones of the lower member of the shallow-water limestone sequence intercalating basaltic volcaniclastic rocks. Locality is shown in Plate 1A.

D. The irregular stylolite boundary between huge limestone rock-masses in the Hikone quarry. Locality is shown in Figure 3.

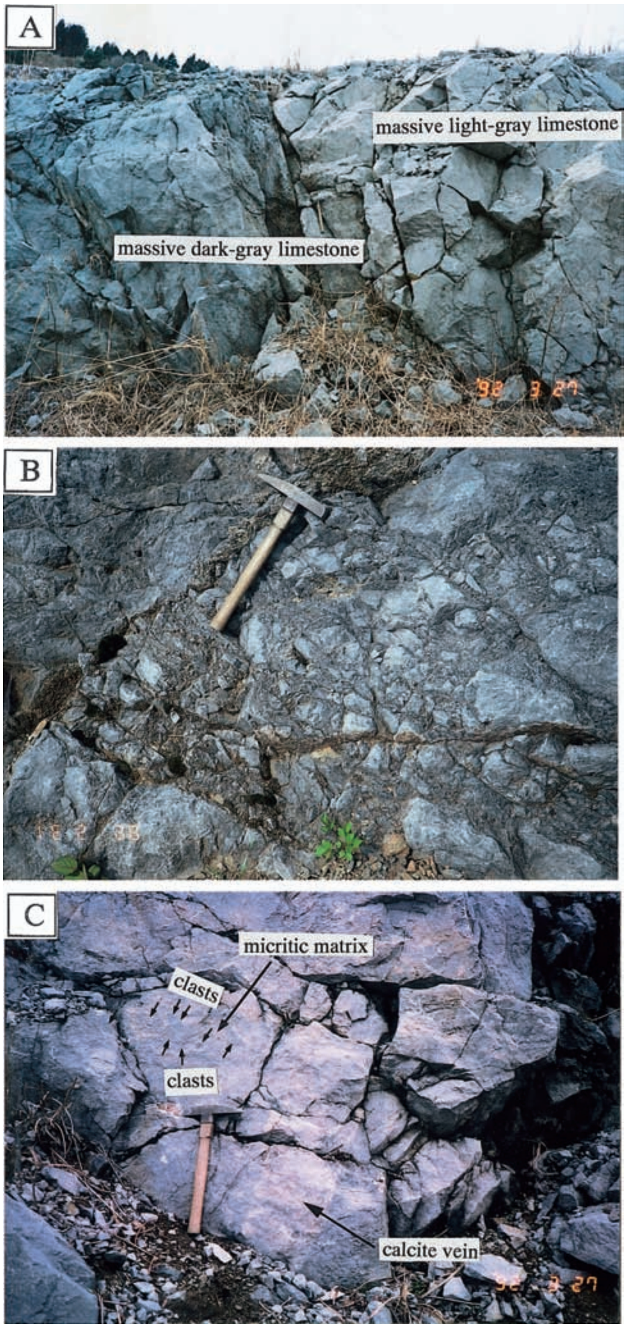

Plate 3. Outcrop views of the middle and upper members of the shallow-water limestone sequence in the Hikone quarry

Localities are shown in Plate 1B.

A. The boundary between dark-gray and light-gray limestones. The boundary is vague.

B. The dolomitized limestones of the middle member.

C. The limestone-breccia of the upper member of the shallow-water limestone sequence. The clasts of various limestone-types (dark gray parts) are surrounded in the lime-mud matrix (light-gray parts).

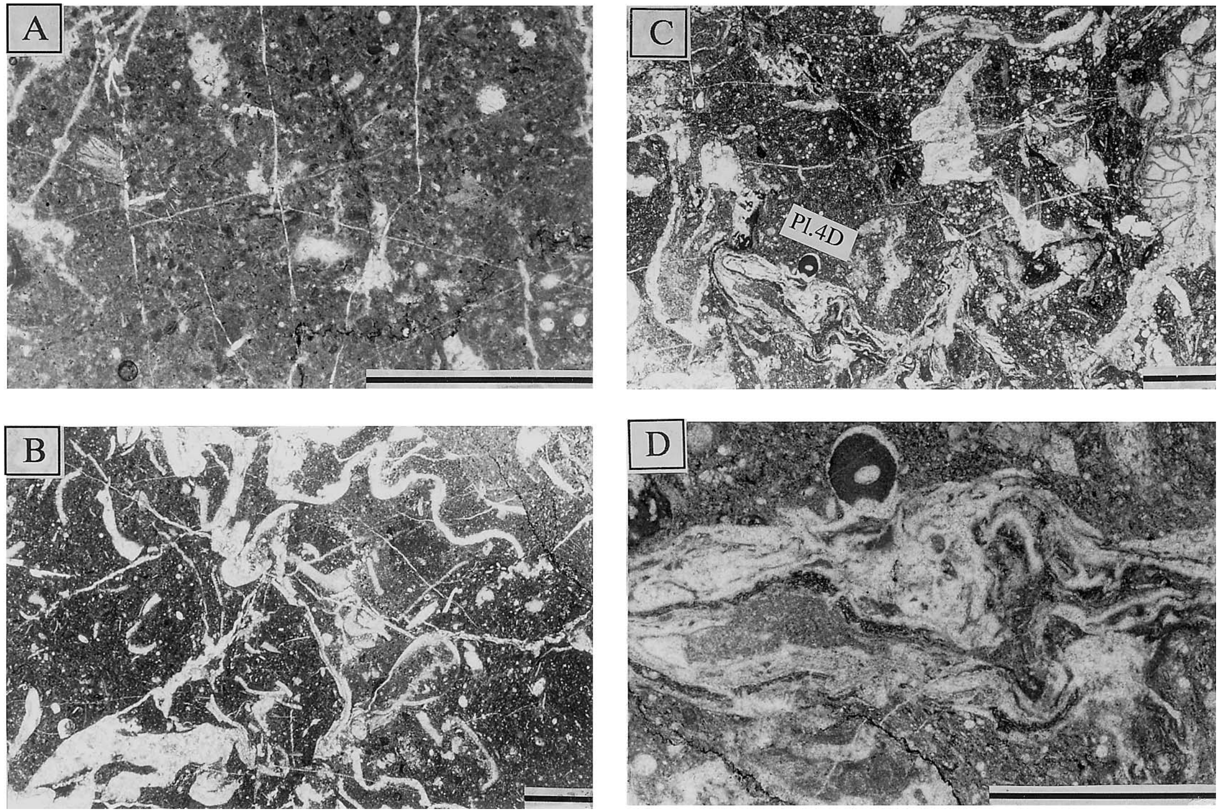

Plate 4. Photomicrographs of the shallow-water limestones

Plane light. All scale bars: 2.5 mm.

A. Peloidal lime-mudstone. Minute bioclastic debris are scattered in a peloidal lime-mud matrix.

B. Bivalve lime-wackestone with a poor-sorted peloidal lime-silt matrix. Most of skeletal debris comprise bivalve shells. A small amount of ostracods and the small foraminifers is associated.

C and D. Bioclastic lime-wackestone. Red algae form thin veneers of algal mat.

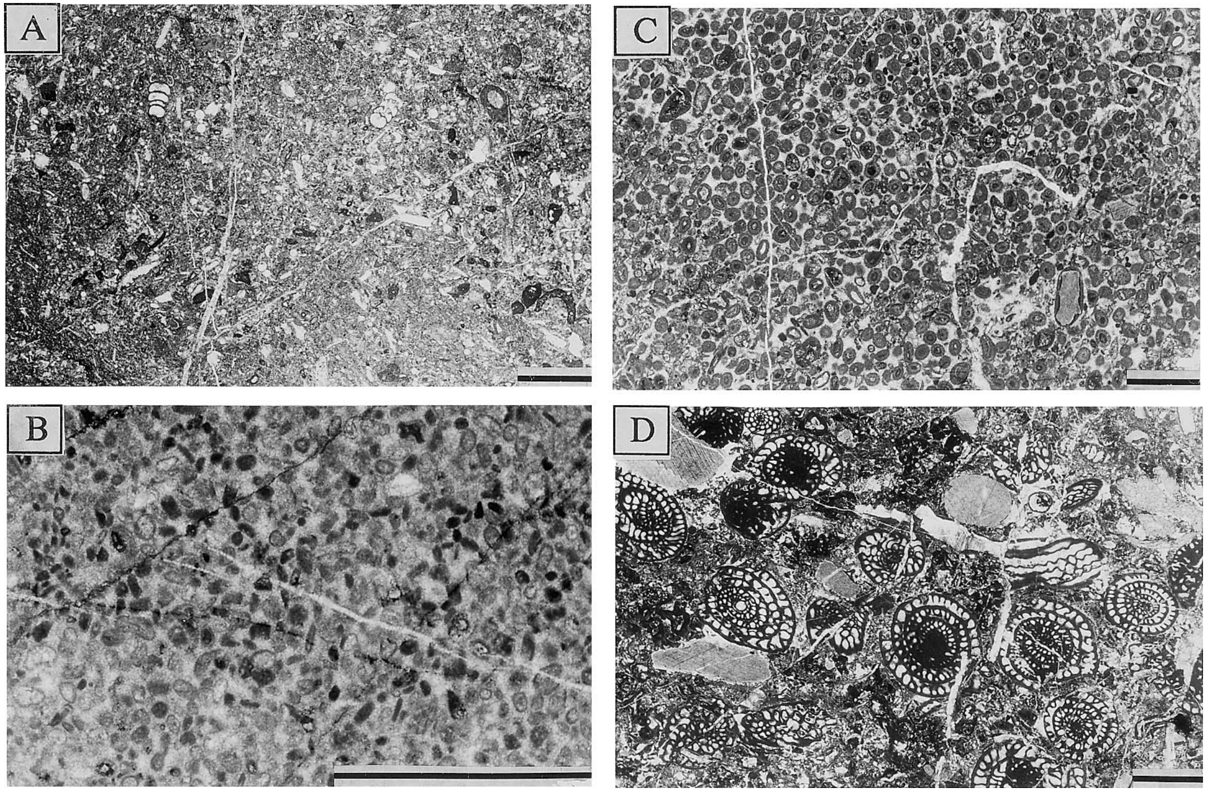

Plate 5. Photomicrographs of the shallow-water limestones

Plane light. All scale bars: 2.5 mm.

A. Bioclastic lime-mud/wackestone. Skeletal debris include the small foraminifers, thin-shelled bivalves, calcispheres, ostracods, and cyanobacterias, all embedded in a poor-sorted bioclastic lime-silt matrix

B. Peloidal lime-grainstone. Well-sorted peloids are dense-packed and cemented by recrystallized sparry calcite. Rounded, cylindrical-shaped peloids are probably derived from girvanellid cyanophytes.

C. Oolitic lime-grainstone. Nuclei of ooids comprise sparry carbonate grains, peloids and crinoids.

D. Crinoid-fusuline lime-wacke/packstone. Fusulines and a small amount of crinoids are largely supported by each other.

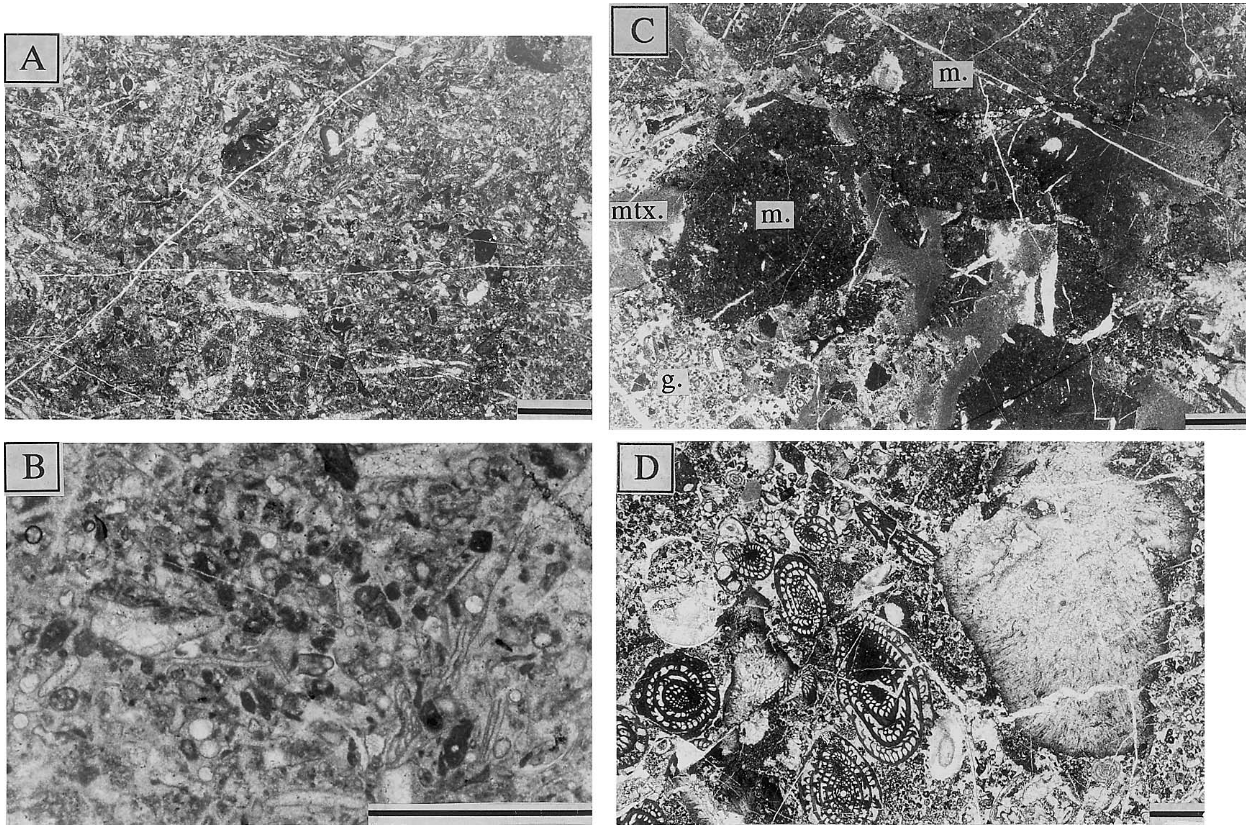

Plate 6. Photomicrographs of the shallow-water limestones

Plane light. All scale bars: 2.5 mm.

A. Algal lime-wackestone. Most of skeletal debris are cyanophytes. A small amount of calcispheres, the small foraminifers, bivalves, and peloids is discerned.

B. Algal lime-wackestone. Short tubes are cyanophytes. Close-up view of Plate 6A.

C. Limestone-breccia. Polymictic limestone-breccia has angular, unsorted limestone lithoclasts chaotically embedded in a well-sorted lime-mud matrix. Lithoclasts are supported by one another. mtx.: lime-mud matrix, m.: bioclastic lime-mudstone, g.: algal lime-grainstone.

D. Fusuline peloidal lime-grainstone. Fusulines, a large mass of cyanophytes, and diverse skeletal particles are dense-packed within peloidal matrix. Local sparry cements occur.

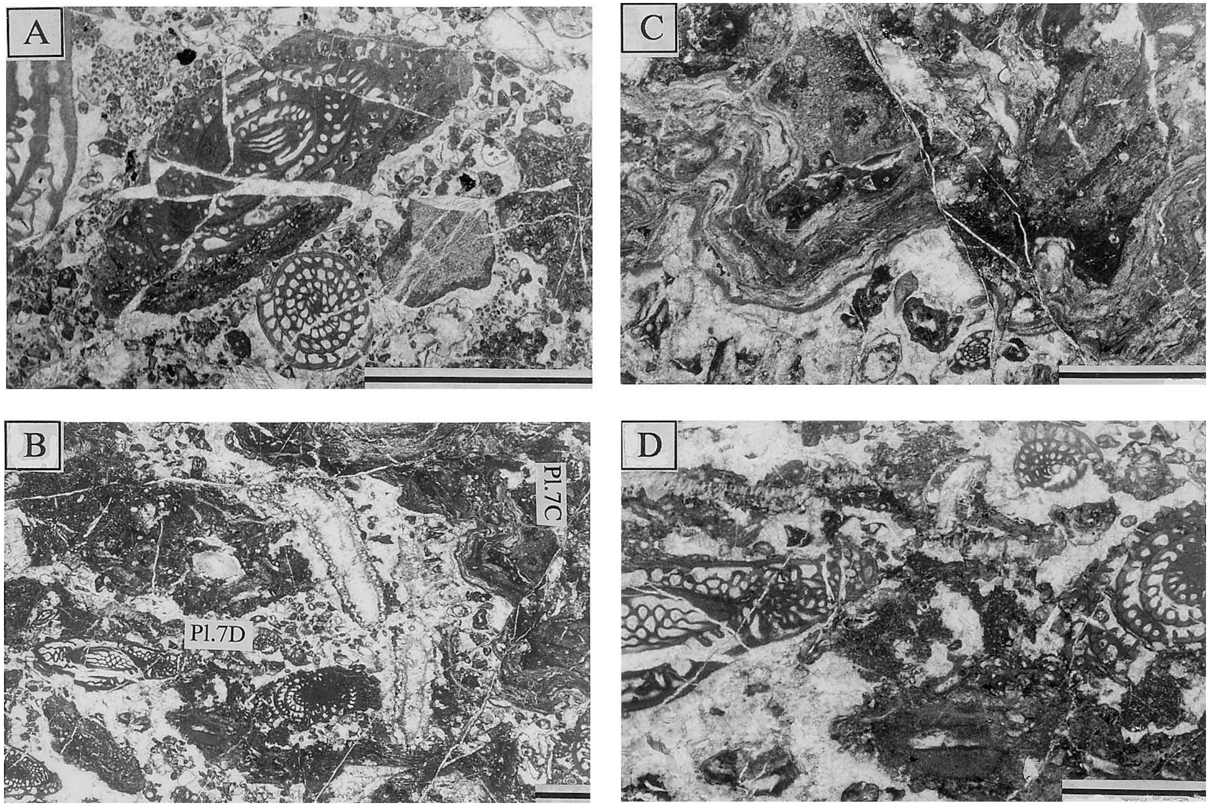

Plate 7. Photomicrographs of the shallow-water limestones
Plane light. All scale bars: 2.5 mm.

A. Fusuline peloidal lime-grainstone. Fusulines and crinoids are coated by algal micrite.
B. Algal bindstone with primary open-spaces filled by sparry calcite. Cyanobacterias bindstone is encrusted by red algae.
C. Cyanobacterias algal bindstone. Rock framework incorporates fusulines, green algae, bivalves, and the smaller foraminifers. Open spaces are filled by sparry calcite. Close-up view of Plate 7B.
D. Red algae, probably Archaeodispoleum forms algal mats consisting of alternating micrite layers and layers of sparry calcite. Close-up view of fine lamellar structure in Plate 7B.