PERMIAN OCEANIC-ROCKS OF MINO TERRANE, CENTRAL JAPAN
PART II. LIMESTONE FACIES*

HIROYOSHI SANO**

Abstract  The stratigraphy, age, and limestone petrography of the Funabuseyama Formation of limestone facies, one of the Permian oceanic rock-units of the Funabuseyama mass in the northwestern Mino Mountains, were examined.

The formation is a thick pile, up to 800 m thick, of shallow-marine limestones with basaltic volcaniclastics in the basal part. The lower part of the formation (Pseudofusulina ambigua Zone) consists mostly of black, bedded, highly carbonaceous, algal and molluscan wackestones, with some interbeds of laminated bioclastic packstone. The middle (Parafusulina kaerimizensis Zone) comprises light grey, structureless, fusuline-crinoïd wackestone and intraclastic bioclastic grainstone. The upper (Neoschwagerina marginata-Yabeina globosa Zone) is composed of dark grey structureless to thick-bedded, fusuline wacke/packstone.

It is evident that all of the limestones have formed in very shallow-marine environments. The wackestones and wacke/packstone are believed to have accumulated in calm lagoonal basins. The intraclastic bioclastic grainstone is interpreted as washed skeletal sand deposits on sand bars and shoals. The laminated bioclastic packstone is ascribed to deposits derived by intermittent storms and spring tides from the sand bars and shoals into the lagoonal basins.

All lines of evidence lead to the interpretation that the limestones are of a bank-formed shallow-marine buildup most possibly on a basaltic seamount in an open-ocean setting.

Introduction

The rock-association of Permian greenstone, chert, and carbonate rock occurs as big allochthons in the Jurassic sedimentary complex of the Mino Terrane. The Funabuseyama mass (Fig. 1), lying in the northwestern part of the Mino Mountains, is one of the representatives of the allochthons.

As introduced by SANO (1988), nearly coeval three rock-units are identified in the Funabuseyama mass: Hashikadani Formation consisting mainly of greenstone of basaltic lavas and volcaniclastics, chert, and dolomite, Funabuseyama Formation mostly comprising limestone, and Amanokawara Formation characterized by limestone-breccia with greenstone, limestone, and dolomite.

Continued from the stratigraphic description of the Hashikadani Formation (SANO, 1988), the paper describes lithostratigraphy and fusuline biostratigraphy of the Funabuseyama Formation with brief notes on the petrography.

Received July 11, 1988. Accepted October 18, 1988.

* A part of this study was read by the author at the Joint Meeting of Kansai and Nishinihon Branches of the Geological Society of Japan, at Tokushima, 1987 (SANO and KUMAMOTO, 1987).

** Dept. Geol., Fac. Sci., Kyushu Univ., Fukuoka, 812 Japan.

Fig. 1. Location map, Mt. Funabuseyama area, northwestern Mino Mountains, central Japan.
of the limestone. Depositional environments of the limestone are also given with a schematic diagram.

**Acknowledgments**

The author thanks Dr. K. Kanmera (Professor Emeritus, Kyushu Univ.), who critically read the early draft of the manuscript and identified fusulines. The author also thanks Prof. A. Aihara (Kyushu Univ.) for his helpful advice on the geochemistry of the organic matter in the examined limestone. Thanks are due to Miss Y. Kumamoto (Nippon Mining Co. Ltd.) and Mr. K. Horibo (Kyushu Univ.), who kindly permitted the author to refer to their unpublished data (Kumamoto, 1987MS; Horibo, 1988MS).
Fig. 3. Geologic map of Mt. Funabuseyama area, revised after SANO (1988).
A=Amanokawara Plateau, F=Mt. Funabuseyama, Hg=Hashigatani Gully, Hs=Hashikadani G., Iw=Iwaidani G., Kh=Kashiiradani G., Nt=Natsuusakadani G., W=Waidani G., Kz=Kanzakigawa River, Nh=Neohigashidanigawa R.

Litho- and biostratigraphy of Funabuseyama Formation

Stratigraphic division

Overall Permian carbonate rocks of the Funabuseyama mass have been designated as a single rock-unit by some workers (FUJIMOTO et al., 1962; KAWAI, 1964; NAKAMURA, 1966), who have roughly described it only as comprising basaltic rocks below and carbonate rocks above. As outlined in the introductory note, however, the Funabuseyama and Amanokawara Formations have lithologies largely different from each other but are nearly coeval with each other. The former is a thick pile of shallow-water limestones with
various lithologies, and hence can be termed limestone facies, whereas the latter is characterized by limestone-breccias closely associated with basaltic lavas and volcanoclastic, limestones, and dolomites, hence limestone-breccia facies (see also Fig. 2 of SANO, 1988). The two formations are always in fault contact. Thus, the two formations are the rock-units to be clearly discriminated from each other.

**Lithostratigraphy**

Rocks of the Funabuseyama Formation are exposed along the Neohigashidaniigawa and Kanzakigawa Rivers and cover the greater part of Mt. Funabuseyama (Fig. 3).

The formation consists mostly of fossiliferous, shallow-marine limestones with various lithologies and has thin interbeds of basaltic volcanoclastics in the lowest part (Fig. 4). Thickness of the formation attains up to 800 m. Its top and bottom are invariably cut by faults.

Lithologically, the formation is subdivided into the following three members (Figs. 4, 5); the lower characterized by black, bedded limestone with the volcanoclastic beds, the middle composed of light grey, structureless limestone, and the upper comprising dark grey, structureless to thick-bedded limestone. Neither coarse-grained terrigenous clastic rocks nor grains occur in the whole succession.

(i) **lower member** (approximately 200 m thick)

The succession can be best observed along the Neohigashidaniigawa River and the mid-reaches of the Hashikadani Gully (Fig. 3).
The narrow outcrops are found out along the Kanzakigawa River and Kashiharadani Gully. The basaltic volcaniclastics in the lower part (Figs. 4, 5) are dark green or brownish red, comprise sand- to silt-sized basaltic detritus, and are crudely laminated. Their thickness considerably varies laterally, ranging from several tens of centimeters to several meters.

Fresh rocks of the limestone are black (N 1; Rock-Color Chart: Geol. Soc. Amer., 1984) or greyish black (N 2), carbonaceous, and smells putrid. Preliminary X-ray diffraction analysis of hydrochloric acid-treated residues reveals that considerable amounts of the weakly graphitized carbonaceous matter are contained in the limestone. These dark colors of the limestone are evidently due to its high content of the carbonaceous matter.

The limestone has distinct bedding structures (Plate I–1, 2); the beds range in thickness from a few tens of centimeters to a few meters, most usually several tens of centimeters. The thickness of beds tends to increase in the lower and upper parts of the member, attaining up to 5 m. Bedding is planar in general, although the wavy bedding appears locally. The limestone beds are often separated by calcareous, carbonaceous matter-rich claystone beds (Plate I–3). The claystone is absolutely black, fragile, and fissile. Minute, fragmented bivalves occur laminated. The claystone beds are usually less than several centimeters thick, rarely up to 30 cm, and laterally discrete. Their top and bottom are indistinct; gradual lithologic changes into over- and underlying limestone beds are common.

A small amount of chert nodules occur embedded in thick-bedded limestone in the lower part (Fig. 5). The nodules are black to dark grey and elliptic to irregularly rugelenticular in form. The limestone of the member is commonly fossiliferous (Plates II–IV), rich in shallow-marine fossils.

The most characteristic fossils of the lower member are calcareous algae (mostly green algae), including Vermiporella nipponica Endo (Plate IV–1, 2) and Mizia velbitana Schubert (Plate IV–3), bivalves, including an allatoconchid bivalvia, Shikamaia oka sakamensis Ozaki (Yancey & Ozaki, 1986; Plate II–3), and
bellerophontid gastropods, including Belleropho-
phone sp. (Plate II–4). Fusulines are not com-
mon in the member, but locally crowded. Smaller
foraminifers, brachiopods, ostracods, crinoids,
and echinoids are subordinate. Bryo-
zoans, sponge spicules, and corals, including
the Waagenophilidae, are present, but very
rare. In addition to these fossils, annelid
worm tubes are occasionally found (Plate
IV–5).

Among the above-described fossils, the bi-
valves, gastropods, fusulines, and green algae
often occur crowded to form laminae, patches,
and even beds (Plates III–2, 3, 4, IV–4).
In such cases, they usually consist of a single
(Plate II–2, 4) or a few species (Plate III–3);
a low species-diversity in each lamina, patch,
and bed. The fossils are not strongly frag-
mented, although bivalve shells have been
usually disjointed.

Most prominent are layers condensed with
thick-shelled bivalves, mostly of Shikamaia
akasakaensis (Fig. 5; Plate II–3). The layers
range in thickness from several to several tens
of centimeters and laterally discrete. Note-
worthy is that minute bioclasts and large-
sized Shikamaia shells coexist, both embedded
in a lime-mud matrix. This means that the
Shikamaia shells have not been reworked by
water currents, but have accumulated nearly
in their life position, as suggested by YANCEY
& OZAKI (1986).

In addition to ordinary geopetal fabrics,
including the half- or incomplete filling struc-
ture (Plate III–2, 3), the convex top of
Vermiporella nipponica encrusting Shikamaia
shells is available for the top and bottom determina-
tion (Plate IV–2).

As to grain-fabrics, the matrix-support is
much dominant over the grain-support in the
lower member. According to the limestone
classification by DUNHAM (1962), most of the
limestones of the lower member are described
as wackestone (Fig. 5), although small amounts
of packstone occur intercalated. It should be
noted that no boundstones occur.

The matrix of the wackestone comprises
lime-mud (e.g., Plates II–4, III–3, –4) or a
mixture of lime-mud or silt and minute
bioclasts (e.g., Plates II–1, –3, IV–3). Both
types of the matrix are densely stained sooty
black by aphanitic carbonaceous matter.

The packstone of the lower member occurs
as intermittent, laterally discrete interbeds,
commonly several tens of centimeters thick,
at a few levels (Fig. 5). It contains diverse
bioclasts including crinoids, echinoids, smaller
foraminifers, fusulines, bivalves, and gas-
tropods and intraclasts of lime-mudstone.
Noteworthy is that crinoids, echinoids, and
intraclasts are very scarce in the above-
described wackestones of the lower member.
The packstone is often crudely laminated,
without intervening lime-mudstone layers.
The embedded bioclasts are weakly abraded
and fragmentary (Plate III–1).

(ii) middle member (up to 550 m thick)

The middle member occupies the south-
eastern to eastern part of the Funabuseyama
mass (Fig. 3). The succession is best observed
along the middle reaches of the Kashiharadani
Gully. The rocks well crop out also along the
upper reaches of the Kanzakigawa River.

The middle member overlies the lower mem-
ber with gradational lithologic changes. The
limestone at the top of the lower member is
medium grey and thick-bedded to structureless,
having megascopic features rather similar to
those of the middle member. Additionally,
black limestone beds occur intercalated at the
bottom of the middle member (Fig. 5–VII).

The limestone of the middle member is
mostly light to medium grey (N 7 to N 5)
(Figs. 4, 5). Without any bedding structures,
the limestone is completely structureless (Plate
I–4). Only rarely seen is parallel allignment
of longer axes of fusulines.

The limestone of the middle member con-
ains many kinds of fossils, intraclasts, and
peloids, all of which are embedded in a lime-
mud matrix (Plate V–1, 2) or cemented by
sparry calcite (Plate V–3).

The most common skeletal debris are fus-
ulines and crinoids, while green algae, smaller
foraminifers, brachiopods, bivalves, gastropods,
echinoids, and ostracods are subordinate. Fu-
sulines and crinoids occur crowded locally.
Bivalves and gastropods are small-sized and
only scattered. No such layers occur that are
condensed with large-sized bivalves and gas-
tropods as seen in the lower member.

The lower and upper parts of the middle member are composed largely of wackestone, and the middle part is characterized by frequent intercalations of sparite-cemented grainstone (Fig. 5).

Although the limestones are more or less dolomitized throughout the overall Funabuseyama Formation, the dolomitization is severe particularly in the middle member. The severe dolomitization has sometimes completely destroyed primary fabrics of the limestone of the middle member.

(iii) **upper member** (approximately 50 to 70 m)

Distribution of the member is narrow and sporadic, restricted to the eastern part of the study area (Fig. 3). The succession can be well observed along the upper reaches of the Kanzakigawa River and along the lower reaches of the Shiraiwadani Gully.

The whole of the upper member consists of dark grey to medium grey (N 3 to N 5), structureless or thick-beded limestone (Figs. 4, 5). The structureless limestone dominates over the bedded one.

The dark grey variety of the limestone is actually carbonaceous. Although the X-ray diffraction analysis has identified weakly graphitized carbon, it appears to be much less concreted than in the limestone of the lower member.

In the succession of the bedded limestone, the beds are usually several tens of centimeters thick, attaining up to a few meters (Plate I–5). The bedding is planar. No partings occur that separate the limestone beds.

The limestone comprises fossils, small amounts of peloids and intraclasts, and a matrix. Bioturbation is sometimes identified.

Fusulines are the most common skeletal component of the member (Plate V–4). Subordinate amounts of crinoids, smaller foraminifers, green algae, bivalves, gastropods, and brachiopods are contained.

Most of the limestones of the member are described as wacke/packstone having a lime-mud matrix. Very small amounts of blocky sparite-cemented, fusuline-crowded grainstone occur.

**Fusuline biostratigraphy**

The age of the Funabuseyama Formation was examined by means of the fusuline biostratigraphy. From the limestones of the study area, 39 fusuline species belonging to 20 genera were yielded. Among them the species available for age determination and of paleontological importance are selected and listed in Table 1 with their sample numbers. The fusulines are omitted in Table 1, which are biostratigraphically insignificant and too poorly preserved to be identified at the species level. Omitted are *Psuedofusulina* sp., *Para-

fusulina* sp., *Neofusulinella* sp., *Rausserella* sp., *Schubertella* sp., *Yangchienia* sp., *Staffella* sp., *Ozawainella* spp., and *Nankinella* spp.

Containing the genera *Psuedofusulina*, *Misel-

лина*, *Cancellina*, *Psuedodoliolina*, *Neoschwagerina*, and others, the fusuline assemblages of the formation are characterized by dominance of *Para-fusulina*.

Within the limestone succession, the following 3 fusuline zones are confirmed in ascending order: *Psuedofusulina ambiguа Zone* of late Early Permian, *Para-fusulina kaerimizensis* Zone of early to middle Middle Permian, and *Neoschwagerina margaritae-Yabeina globosa* Zone of middle to late Middle Permian (Fig. 4). Overall, the Funabuseyama Formation ranges in age from late Early to late Middle Permian.

The lower member belongs to the *Psuedo-
vusulina ambiguа Zone*, in which *P. ambiguа* (**DEPRA**T and *Misellina claudiae* (**DEPRA**T) are characteristic. Subordinate are *Pamirina leveni Kobayashi*, *P. tethydis Kobayashi*, and *Verbe-
kina sphaera Ozawa*. Small amounts of *Para-

fusulina* sp. are contained in the upper part. To be noted is that several species of *Staffella*, *Ozawainella*, and *Nankinella* occur locally crowded (Plate IV–4).

The middle member is referred to as the *Para-fusulina kaerimizensis Zone*. Diagnostic are *P. kaerimizensis* (**OZAWA**), *P. japonica* (**GÜMBEL**), *Psuedodoliolina ozawai Yabe* and *Hanzawa*, and *Cancellina nipponica* (**OZAWA**), *Neoschwagerina simplex Ozawa*, *N. craticulifera* (**SCHWAGER**), and *Codonofusulina* sp.

The upper member is assigned to the *Neoschwagerina margaritae-Yabeina globosa* Zone, characterized by *N. margaritae* (**DEPRA**T), *Y.
Table 1. List of fusulines available for age determination and of paleontological importance and their sample numbers.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Sample numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudofusulina ambigua (Deprat)</td>
<td>223, 226*, 227, 253, 452, 515</td>
</tr>
<tr>
<td>Parafusulina yabei Hanzawa</td>
<td>131*, 133*, 366*, 420, 554*, 555*, 556*</td>
</tr>
<tr>
<td>P. japonica (Giambel)</td>
<td>127, 128, 362, 375, 379, 413, 414, 416*, 418*, 442*, 218*, 316</td>
</tr>
<tr>
<td>P. akasakensis (Ozawa)</td>
<td>382, 485, 488</td>
</tr>
<tr>
<td>Chusenella sp.</td>
<td>477</td>
</tr>
<tr>
<td>Pamirina leveni Kobayashi</td>
<td>431, 477</td>
</tr>
<tr>
<td>P. tethydis Kobayashi</td>
<td>322-13,</td>
</tr>
<tr>
<td>Misellina claudiae (Deprat)</td>
<td>247, 297*, 459, 460, 463*, 477*, 514*</td>
</tr>
<tr>
<td>P. pseudolepida (Deprat)</td>
<td>382, 485, 547, 556*</td>
</tr>
<tr>
<td>P. sp.</td>
<td>322-20</td>
</tr>
<tr>
<td>Maklaya setapit Kanne &amp; Toriyama</td>
<td>101, 370</td>
</tr>
<tr>
<td>Neoschwagerina simplex Ozawa</td>
<td>36, 380*, 429*, 446, 447, 448*, 449*, 462, 539*</td>
</tr>
<tr>
<td>N. craticulifera (Schwager)</td>
<td>322-8, 449</td>
</tr>
<tr>
<td>N. margaritae (Deprat)</td>
<td>28, 322-14*, -16*, -17*, -30, -31, -32, -33, 327*, 381*, 385, 485, 488*</td>
</tr>
<tr>
<td>N. sp.</td>
<td>401*, 406, 430</td>
</tr>
<tr>
<td>Yabeina katoi (Ozawa)</td>
<td>322-34</td>
</tr>
<tr>
<td>Y. globosa (Yabe)</td>
<td>322-19, -20, -21*, -22*,</td>
</tr>
<tr>
<td>Y. sp.</td>
<td>28, 322-24, -25, -26, -38, 450, 488</td>
</tr>
<tr>
<td>Cancellina nipponica (Ozawa)</td>
<td>34, 35, 217, 317, 320, 369, 371, 372, 373, 374, 405*, 410, 411*, 549*</td>
</tr>
<tr>
<td>C. tenuitesta Kannea</td>
<td>32</td>
</tr>
<tr>
<td>C. schellwieni (Deprat)</td>
<td>321*, 362*</td>
</tr>
<tr>
<td>C. sp.</td>
<td>218, 362, 409, 481, 541, 544, 552</td>
</tr>
<tr>
<td>Verbeekina sphaera Ozawa</td>
<td>297</td>
</tr>
<tr>
<td>V. verbeeki (Geinetz)</td>
<td>322-19, -31, 488*</td>
</tr>
<tr>
<td>Minojapanella sp.</td>
<td>471</td>
</tr>
<tr>
<td>Yangchienia compressa (Ozawa)</td>
<td>366</td>
</tr>
<tr>
<td>Y. iniqua Lee</td>
<td>447*</td>
</tr>
<tr>
<td>Neofusulinella lantenoisi Deprat</td>
<td>321</td>
</tr>
<tr>
<td>Toriyamaia sp.</td>
<td>372, 374, 459, 460, 471, 484, 487</td>
</tr>
<tr>
<td>Codonofusiella sp.</td>
<td>131, 133, 152, 322-8, -34, -39, 325, 349, 368, 369, 379, 385, 444, 486, 487, 488, 556</td>
</tr>
<tr>
<td>Nankinella orbicularia Lee</td>
<td>462*</td>
</tr>
</tbody>
</table>

Sample localities are shown in Fig. 2.

globosa (YABE), Y. katoi (OZAWA), and Verbeekina verbeeki (GEINETZ). Chusenella sp. and Codonofusiella sp. are subordinate.

The above-described fusuline biostratigraphy is nearly concordant with the previous results (IGO & OGAWA, 1958; KAWAI, 1964; NAKAMURA, 1966; MATSUMARU, 1966); IGO & OGAWA (1958), for example, identified the
zone of *Pseudoschwagerina*, zone of *Parafusulina*, and zone of *Neoschwagerina* and *Yabeina* in ascending order within the limestone sequence of the Mt. Funabuseyama area.

**Limestone types and depositional environments**

**Limestone types**

For petrographic examination, more than 700 thin-sections were prepared, including large-sized ones, as large as $7 \times 10$ cm.

Names of limestone types described below are based upon fabric types, combined with grain types. Although considerably varied in lithologies, the limestones of the Funabuseyama Formation are grouped into 6 major limestone types; 1) molluscan wackestone, 2) algal wackestone, 3) fusilino wacke/packstone, 4) fusilino-crinoid wackestone, 5) intraclastic bioclastic grainstone, and 6) bioclastic packstone. The minor varieties occur, including bioturbated peloidal lime-mudstone (Plate IV –5, 6), sponge spicule-bearing lime-mudstone, and fossils-poor lime-mudstone. The petrographic characteristics of the 6 major types are given below.

1) **molluscan wackestone** (Plates II–2, 3, 4, III–2):

The limestone of this type comprises abundant bivalve and gastropod shells, their fragments, and a matrix. Small amounts of green algae, brachiopods, ostracods, fusilines, and smaller foraminifers are occasionally associated. The matrix is composed of lime-mud or a mixture of lime-mud to fine-grained lime-silt and minute bioclastic grains. All skeletal components are supported by the matrix.

According to kinds of shells, a few varieties are recognized; small-sized and thin-shelled bivalve wackestone, large-sized and thick-shelled bivalve (mostly *Shikamaia akasakaensis*) wackestone, and gastropod lime-wackestone.

The bivalve and gastropod shells occur condensed to form layers. To be stressed is that these layers are occupied by a large number of individuals exclusively of a single or a few species. These features are assigned to have resulted from mass production and perishment of the bivalves and gastropods under intermittent, fertile conditions.

This type is peculiar to the lower member (Fig. 5).

2) **algal wackestone** (Plate IV–3):

Accompanied by small amounts of bivalves, gastropods, fusilines, and smaller foraminifers, the green algae, including the genera *Vermiporella* and *Mizizia*, are the essential skeletal component of this type. The algae and other skeletal grains are supported by a matrix comprising a mixture of lime-mud or silt and minute bioclasts and containing considerable amounts of aphanitic carbonaceous matter.

This type occurs restrictedly in the lower member (Fig. 5).

3) **fusilino wacke/packstone** (Plates IV–4, V–1, 4):

The limestone of this type is characterized by abundant fusilines, with small amounts of crinoids, green algae, smaller foraminifers, bivalves, brachiopods, and ostracods. In many cases, these skeletal debris are randomly embedded in and supported by a matrix composed essentially of lime-mud with some tiny bioclasts and peloids or partly grain-supported (Plate V–1, 4). Fusilines are weakly abraded and fragmented. Locally, however, the distinct grain-support fabric is seen in the limestone, where a large number of fusilino individuals exclusively of a single species, including a species of *Staffella*, *Nankinella* or *Ozawainella*, are dense-packed with the narrow micritic matrix (Plate IV–4).

The fusilino wacke/packstone is common in the upper member (Fig. 5), and is found also in the lower and middle members.

4) **fusilino-crinoid wackestone** (Plate V–2):

Essential skeletal debris of this type are crinoids and fusilines. The former dominates over the latter and occurs crowded to form the limestone to be termed encrinitic limestone in places. Associated with crinoids and fusilines, small amounts of echinoids, green algae, smaller foraminifers, ostracods, brachiopods, and bivalves are contained.

All these skeletal components are supported by a lime-mud matrix with small amounts of minute bioclastic debris and peloids.

This type occupies a large part of the middle
member, and is found out also at the top of the lower member (Fig. 5).

5) *intraclastic bioclastic grainstone* (Plate V–3):

Characteristic of this type is that considerable amounts of intraclasts are contained together with bioclasts. The intraclasts are mostly composed of bioclastic wackestones. The bioclastic components of this type include fusulines, smaller foraminifers, crinoids, echinoids, green algae, brachiopods, bivalves, and gastropods. Noteworthy is that both of the intraclastic and bioclastic grains are well sorted and often strongly abraded. Although micritic matrix rarely found out, these grains are usually supported by one another and cemented by sparite.

This type occurs at several levels of the middle member (Fig. 5).

6) *bioclastic packstone* (Plate III–1):

The limestone of this type contains weakly abraded and fragmented, diverse bioclasts, including fusulines, crinoids, bivalves, gastropods, smaller foraminifers, ostracods, and echinoids, and varied amounts of intraclasts mostly of lime-mudstone. The bioclastic and intraclastic grains are dense-packed and supported by one another. Both of sparite cement and fine-grained lime-silt to lime-mud matrix occur.

Distinct features of this type is that the grains are sorted and often exhibit faint parallel lamination. In places, even graded laminae are found.

The limestone of this type and the above-described intraclastic bioclastic grainstone are similar in the grain type and nature of the groundmass to each other. The limestone of this type, however, can be distinguished in having lamination and fine sand- to silt-sized particles in a matrix from the intraclastic bioclastic grainstone.

This type occurs as intermittent, laterally discrete, thin beds in the wackestones of the lower member (Fig. 5).

**Depositional setting**

To be stressed is that no terrigenous clastic materials coarser than the mud-size occur throughout the limestone succession of the Funabuseyama Formation. No terrigenous rock-units are present that laterally nor vertically pass into the Funabuseyama Formation. These facts mean that the Funabuseyama Formation was formed in an open-ocean setting without any input of coarse-grained terrigenous clastic materials.

All skeletal debris identified from the limestones of the Funabuseyama Formation are indicative of their accumulation in shallow marine environments. Common occurrence of green algae suggests deposition of the limestones in very shallow-depths.

As to the pedestal of the limestones, the basaltic basement is most likely. This interpretation is inferred from intercalation of basaltic volcanics in the lowest part of the limestone succession herein examined, and is supported by the fact that a thick succession of basaltic lavas and volcanics underlies shallow-water carbonate rocks of the Amanokawara Formation, which is nearly coeval to the Funabuseyama Formation (see Fig. 2 of SANO, 1988). Thus, the limestones of the Funabuseyama Formation were formed as shallow-water limestone-buildup resting upon a basaltic mound, including a seamount, in an open-ocean setting.

**Depositional environments**

All lines of stratigraphical, sedimentological, and paleontological evidence lead to the following interpretation on depositional environments of the limestones of the Funabuseyama Formation (Fig. 6).

The wackestones and wacke/packstones are interpreted as sediments in flat, shallow, and calm lagoonal basins. Particularly, the absolutely black wackestones of the lower member might have accumulated in poorly wave-agitated, poorly circulated, and reducing water environments, where ecologically conditions have been rigorous in general, but intermittently fertile, resulting in mass production and perishment of benthic organisms. Water circulations in the lagoonal basins have been less restricted during accumulation of the middle member.

The intraclastic bioclastic grainstone of the middle member is assigned to have accumulated on sand bars and shoals, where skeletal sands have been well washed and
sorted by water currents or agitation; relatively high water energies on sand bars and shoals.

The bioclastic packstone of the member is ascribed to storm-generated deposits, having been derived from the sand bars and shoals into the lagoonal basins by intermittent storms or related spring tides.

In summary, most limestones of the Funabuseyama Formation are ascribed to shallow-marine lagoonal sediments, accompanied by intermittent storm or spring tide deposits in the lower and the sand bar and shoal sediments in the middle (Fig. 4). The overall limestones are interpreted as a remnant of a bank-formed limestone buildup on a basaltic pedestal.

This limestone buildup is inferred to have been accompanied with a possible foreslope and offshore terrace (Fig. 6). Sediments on the foreslope and offshore terrace could be represented by the limestone-breccia and limestone of the Amanokawara Formation, respectively, which is to be detailed in Part III.

Summary

The Funabuseyama Formation is of a thick pile, up to 800 m thick, of shallow-marine limestones with varied lithologies, accompanied with thin intercalations of basaltic volcanics in the lowest part. No terrigenous clastic rocks occur throughout the succession. The age ranges from the late Early to late Middle Permian; the Pseudo fusulina ambigua Zone, Parafusulina kaerimizensis Zone, and Neoschwagerina marginatae-Yabeina globosa Zone were recognized in ascending order.

The limestone succession is divided into the lower, middle, and upper members. The lower is characterized by black, carbonaceous matter-rich, bedded algal wackestone and molluscan wackestone with laminated bioclastic packstone. Limestones of the middle are light grey, structureless, and are mostly described as the fusuline-crinoid wackestone and intraclastic bioclastic grainstone. The upper member comprises dark grey and structureless to thick-bedded fusuline wacke/packstone.

All skeletal debris indicate accumulation of the limestones in very shallow-water depths. The wackestones which predominate through the succession are interpreted as sediments in calm lagoonal basins. The laminated bioclastic packstone of the lower member is ascribed to storm-generated deposits. The in-
tracelastic bioclastic grainstone in the middle is assigned to washed skeletal sand deposits on sand bars and shoals with higher water-energies.

The limestones of the Funabuseyama Formation were a shallow-water limestone buildup on a possible seamount in an open-ocean setting.

References


GEOL. SOC. AMER., 1984: Rock-Color Chart.


NAKAMURA, M., 1966: Lithology of Funabuseyama Limestone. Sekkkeiseki (Limestones), 101, 7–20.**


**: in Japanese.
Explanations of Plates

Plate I. Outcrop photographs of limestones of Funabuseyama Formation.
1. Typical view of black bedded limestone of lower member. For scale note person in left of view. Photographed at locality marked as 247 in Fig. 2. Along Nohigashidanigawa River.
2. Close up view of bedding style of black bedded limestone of lower member. Bedding is nearly planar. Same locality as that of Plate I—1.
3. Close up view of carbonaceous matter-rich claystone interbed separating limestone beds of lower member. Limestone immediately above claystone interbed contains abundant thick-shelled bivalves (mostly Shikamaia akasakaensis Ozaki) in upper left of view. Note that claystone is less resistant to weathering than limestone. Same locality as that of Plate I—1.
4. Common view of light grey structureless limestone of middle member. Limestone is severely fractured. Over view. For scale note hammer in lower left of view. At locality marked as 30 in Fig. 2. Along Shiraiwadani Gully.
5. Thick-bedded limestone of upper member. No partings occur that separate limestone beds. Outcrop is about 5 m wide. At locality marked as 322 in Fig. 2. Along Kanzakigawa River.

Plate II. Thin-section photomicrographs of limestones of lower member of Funabuseyama Formation. Plane light. All sample localities are shown in Fig. 2.
1. Wackestone with diverse skeletal debris. Skeletal debris include bivalves (1), smaller foraminifers (2), fusulines, Mizia valentana Schubert (3), and indeterminable minute bioclasts coated by green algae, including Vermoporella nipponica Endo. Note that matrix composed of lime-mud and fine bioclastic particles is speckled with aphanitic carbonaceous matter. Sample 327—4. See Fig. 5 for stratigraphic position. Scale bar 1 mm.
2. Molluscan lime-wackestone with thin-shelled bivalves. Small-sized and thin-shelled bivalves are crudely laminated and supported by matrix consisting of lime-mud with dense staining by aphanitic carbonaceous matter. Sample 199. Scale bar 1 cm.
3. Molluscan lime-wackestone with thick-shelled bivalves. Large-sized and thick shells of Shikamaia akasakaensis are supported by matrix comprising lime-mud to silt with fine-grained bioclasts. Note encrusting of Vermoporella nipponica (1) on and algal borings (2) along shell surface of Shikamaia akasakaensis. Encrusting by Vermoporella is enlarged in Plate IV—2. Sample 384. Scale bar 1 cm.
4. Molluscan lime-wackestone crowded with bellerophonid gastropods. Matrix is composed of peloids-rich lime-mud. Sample 100. Scale bar 1 cm.

Plate III. Thin-section photomicrographs of limestone of lower member of Funabuseyama Formation. Sample localities are shown in Fig. 2. Plane light. All scale bars represent 1 cm.
1. Laminated bioclastic lime-packstone. Gastropod—1, bivalve—2, and crinoid—3, intraclasts of lime-mudstone—4. Larger-sized particles are mostly grain-supported, and embedded within fine lime-mud and silt matrix in lower and upper parts of photomicrograph and cemented by sparry calcite in middle part. Sample number 253—2. See Fig. 5 for stratigraphic position.
2. Laminated molluscan lime-wackestone. Note geopetal fabric (incomplete filling structure) seen in bivalve shell (1). Sample 528—1. See Fig. 5 for stratigraphic position.
3. Gastropods- and bivalves-condensed band intercalated within bioclastic lime-mudstone. Note gastropods (1) occur together with minute bivalve shells (2), both embedded within extremely fine-grained lime-mud matrix. Stratigraphic top is indicated by incomplete filling structure (3) seen in gastropod shells. Sample K 82.
Plate IV. Thin-section photomicrographs of limestone of lower member of Funabuseyama Formation. Sample localities are shown in Fig. 2.

1. Close-up view of *Vermiporella nipponica* ESDO. Sample 143. See Fig. 5 for stratigraphic position. Scale bar 1 mm.
2. Enlarged feature of encrusting of *Vermiporella nipponica* on *Shikamia aokakazuensis* shell. Note convex form, which is available for top and bottom determination. Underlying *Shikamia*'s shell is micritized by algal borings. Sample 384. Scale bar 1 mm.
3. Algal lime-wackestone with disintegrated *Mizzia velebitana* SCHUBERT. *Mizzia velebitana* (1) are scattered together with small amounts of smaller foraminifers (2), gastropods (3), and brachiopods (4) in matrix of lime-mud and fine-grained bioclasts. Sample 247–3. See Fig. 5 for stratigraphic position. Scale bar 1 cm.
4. Fusuline lime-packstone. Fusulines (mostly *Staella* sp.) are crowded and densely packed within narrow micritic matrix. Sample 101. Scale bar 1 mm.
5. Worm tubes seen in bioclastic peloidal lime-mudstone. Matrix is rich in fecal pellets. Walls of worm tubes are crudely laminated and composed of sparry calcite. Gastropod shell (1) in center. Sample 137. Scale bar 1 cm.
6. Close-up view of fecal pellets. Pellets are partly cemented by sparry calcite. Same sample as that of Plate IV–5. Scale bar 1 mm.

Plate V. Thin-section photomicrographs of limestones of middle and upper members of Funabuseyama Formation. Sample localities are shown in Fig. 2. Plane light. Scale bars 1 cm.

1. Fusuline lime-wacke/packstone. Fusulines and small amounts of crinoids are supported by lime-mud matrix or by one another. Middle member. Sample 325, yielding *Parafusulina kairimizenis* (OZAWA) and *Codonofusilina* sp. See Fig. 5 for stratigraphic position.
2. Fusuline-crinoid lime-wackestone. Lime-mud matrix is weakly dolomitized, as seen in upper part of photomicrograph (1). Middle member. Sample 153. See Fig. 5 for stratigraphic position.
3. Intraclastic bioclastic lime-grainstone. Embedded particles, fusuline (1), crinoid (2), *Mizzia* (3), bivalve? (4), and intraclasts (5) are abraded. Note isopachous growth of fibrous calcite cement (6). Sample 374. Middle member. Stratigraphic position is shown in Fig. 5.
4. Fusuline lime-wacke/packstone of upper member. Fusulines, including *Verbeekina verbeeki* (GRINETZ) and *Yabeina* sp., are mostly supported by matrix, but are partly grain supported. Matrix comprises peloidal lime-mud. Sample 488. See Fig. 5 for stratigraphic position.