Geology and Sedimentary Environments of the Pleistocene Setana Formation in the Kuromatsunai District, Southwestern Hokkaido, Japan

Reishi Takashima[1,*], Matthew H. Dick[2], Hiroshi Nishi[3], Shunsuke F. Mawatari[3], Ayumu Nojo[4], Masato Hirose[3], Pitambar Gautam[2], Keiichi Nakamura[3] and Takayuki Tanaka[1]

[1]*School of Marine Science and Technology, Tokai University, Shizuoka, Japan*
[2]*COE for Neo-Science of Natural History, Faculty of Science, Hokkaido University, Sapporo, Japan*
[3]*Department of Natural History Sciences, Faculty of Science, Hokkaido University, Sapporo, Japan*
[4]*Department of Science Education, Iwamizawa College, Hokkaido University of Education, Iwamizawa, Japan*

ABSTRACT

The Pleistocene Setana Formation is exposed along the axial zone of the Kuromatsunai district, southwestern Hokkaido Island, and is divided into the Nakasato Conglomerate Member and Soebetsu Sandstone Member. The Nakasato Conglomerate Member consists of medium- to coarse-grained sandstone that accumulated in shoreface, delta, and channel systems. This member is correlated with the overlapping interval between the CN13b calcareous nannofossil zone and the *Neogloboquadrina pachyderma* (s) / *Neogloboquadrina incompta* planktonic foraminiferan zone, which indicates an age of 1.2–1.0 Ma. The Soebetsu Sandstone Member is made up of sandy siltstone to very fine-grained sandstone and includes several beds of shell concentrations. This member is correlated with the CN14a calcareous nannofossil zone and is thought to range in age from 1.0–0.6 Ma. The Setana Formation contains abundant and well-preserved molluscs, bryozoans, and planktonic and benthic foraminifera. Paleoclimatic reconstructions based on the molluscan and planktonic foraminiferan faunas, and on oxygen isotope ratios from planktonic foraminifera, indicate that the basal part of the Nakasato Sandstone Member was deposited during a cooler climate than that of the present Kuromatsunai district, while the lower and middle parts of the Soebetsu Sandstone Member were deposited when the climate was warmer than at present. The Setana Formation, together with other Pleistocene deposits in Japan, has the potential to become a model system for studies on the effects of climatic change on the composition and diversity of assemblages of benthic marine animals; on how community-level parameters modulate these effects; on the responses of individual taxa to climatic change; and on comparison of various proxies used to assess paleoclimate and climatic change.

Keywords: Bryozoa, Pleistocene, Setana Formation, Kuromatsunai, Hokkaido

INTRODUCTION

Bryozoans are common in Neogene deposits in Japan; the first report [1] included 77 species of cheilostomes and cyclostomes representing 55 genera from the Pleistocene Jizodo Formation, Boso Peninsula, Chiba Prefecture. A checklist [2] of all Japanese Cenozoic Bryozoa reported as of 1978 was

*Corresponding author, e-mail: taka4@scc.u-tokai.ac.jp
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published in 1980, listing about 415 taxa; a more recent tally [3] indicates that roughly 358 bryozoan taxa have been reported from Pleistocene deposits in Japan. The full scope of Neogene bryozoan diversity in Japan has yet to be ascertained, and it is important to seek additional bryozoan fossil localities for this purpose.

Although the Pleistocene Setana Formation was previously known to contain bryozoan fossils, high abundance and diversity and exceptionally good preservation of bryozoans in sections of this formation were only recently discovered. Studies analyzing foraminiferal and molluscan assemblages as well as oxygen isotope ratios of benthic and planktonic foraminifera [4–6] have demonstrated that paleoclimatic changes occurred during the accumulation of this formation. This paper presents an overview of the geology and sedimentary environments of the Setana Formation and discusses modes of bryozoan occurrence there.

REGIONAL GEOLOGIC SETTING

Rocks of the Kuromatsunai district consist of Mesozoic basement (Jurassic accretionary complex and Cretaceous granitic rocks), Neogene volcanic and sedimentary rocks (Kunnui, Yakumo, and Kuromatsunai Formations), and Pleistocene (Setana, Warabitai, and Chiraigawa Formations) and Holocene sedimentary rocks (Fig. 1) [7–9].

The Pleistocene Setana Formation unconformably overlies the Pliocene Kuromatsunai Formation, which consists of sandstone, siltstone, and andesitic volcanic and volcaniclastic rocks. The Setana Formation is distributed along the axial zone of the Kuromatsunai district, the so-called Kuromatsunai Lowland Area. The Kuromatsunai Lowland Area is considered to have been a narrow strait between the Sea of Japan and the Pacific Ocean during the deposition of the Setana Formation (Early and Middle Pleistocene). The Setana Formation is unconformably covered by fluvial and lake deposits of the Chiraigawa Formation.

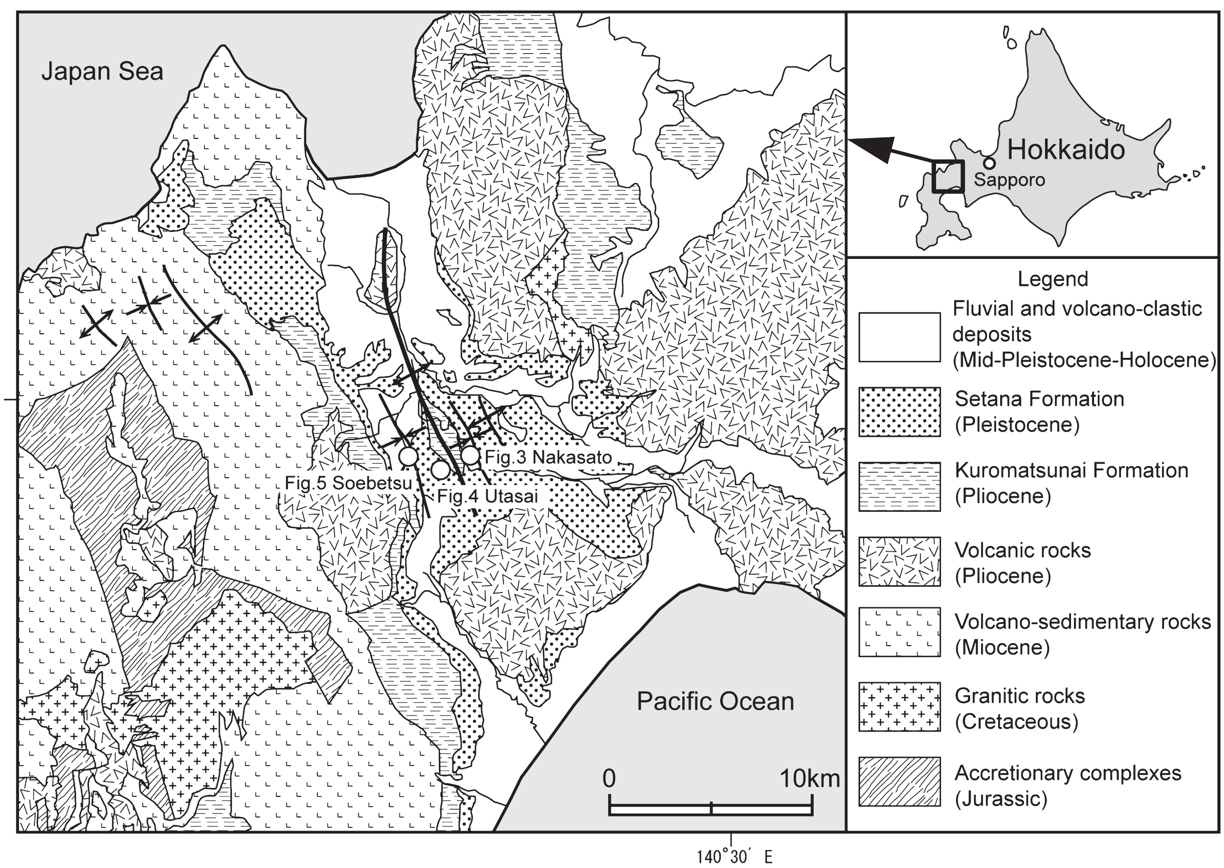

Fig. 1 Geological map of the Kuromatsunai district. Modified from [8–9].

STRATIGRAPHY AND SEDIMENTARY ENVIRONMENTS OF THE SETANA FORMATION

The Setana Formation is lithologically subdivided into the following two members in ascending order [6]: the Nakasato Conglomerate Member and the Soebetsu Sandstone Member (Fig. 2).

Nakasato Conglomerate Member [6]

Type section. Nakasato (42°38′47″N, 140°20′11″ E).

Thickness. < 100 m.

Lithology. This member unconformably overlies the Pliocene Kuromatsunai Formation and is composed of medium- to coarse-grained sandstone and conglomerate. It is further subdivided into lower and upper parts (Fig. 2). Sandstones in the lower part of the member are cross-bedded, while those in the upper part are usually massive (Fig. 2). The lower part, well exposed in the Nakasato section (Fig. 3), consists mainly of cross-bedded, medium- to coarse-grained sandstone, and frequently intercalates thick to very thick beds of conglomerate (Fig. 3A, B). The conglomerate beds are clast-supported with normal grading, and show marked thickness changes as a result of localized deep scour infills. In the conglomerates is gravel comprising subangular to subrounded pebbles and cobbles made of volcanic and volcaniclastic rocks. Fragments of bivalves and gastropods occur abundantly in the conglomerate beds. The upper part of this member crops out at the Utasai Section (another name is Kokemushi Paradise) (Fig. 4). This part is composed of coarse- to very coarse-grained massive conglomeritic sandstone with frequent intercalations of thin- to thick-bedded conglomerate (Fig. 4A). The sandstone contains abundant fragmented echinoids, corals, bivalves, and gastropods, with the last three groups usually encrusted by bryozoans (Fig. 4B, C). The conglomerates are stratified, and are clast- or matrix-supported with normal grading. The gravel in this conglomerate comprises pebble- to cobble-sized volcanic rocks typically heavily encrusted by bryozoans.

Fossils and paleoenvironment. Since most macro fossils of this member are partly broken or fragmented (Fig. 4C), the mode of occurrence is allochthonous. Although the molluscs of this member comprise mainly species of the cool-temperate prov-

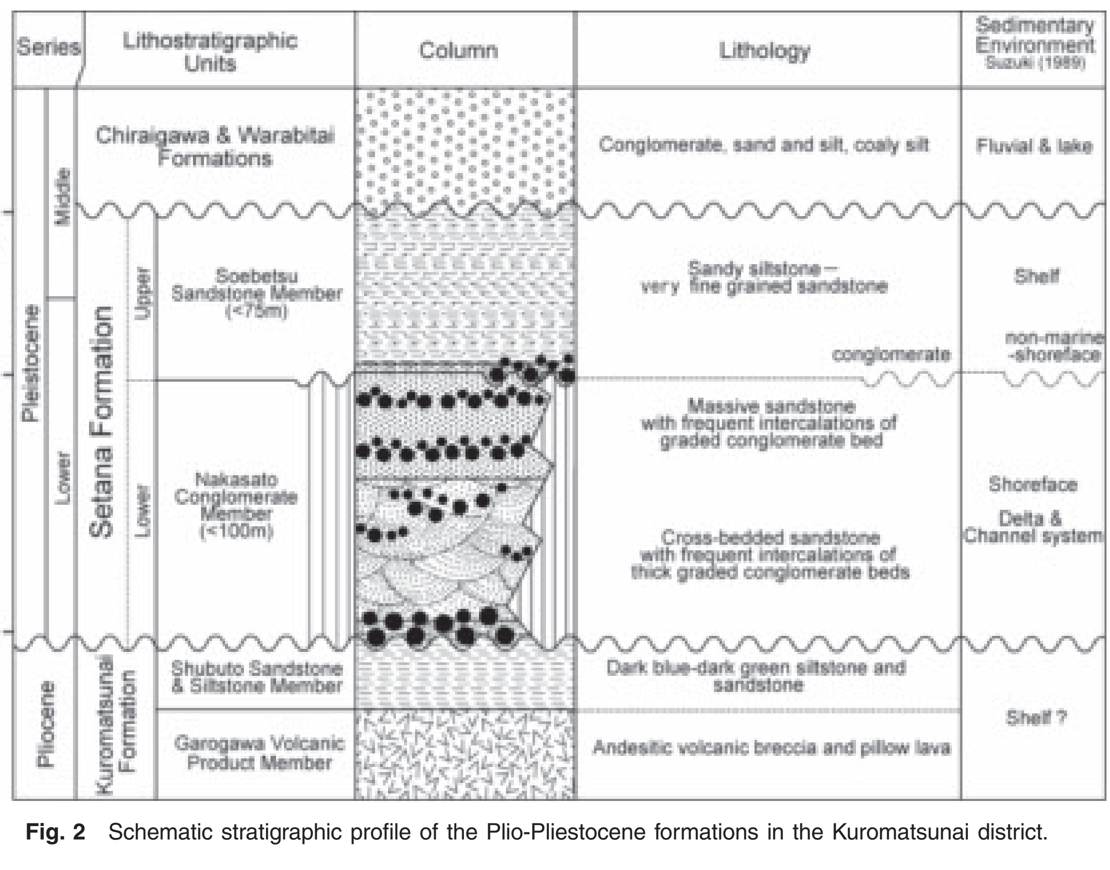

Fig. 2 Schematic stratigraphic profile of the Plio-Pliestocene formations in the Kuromatsunai district.

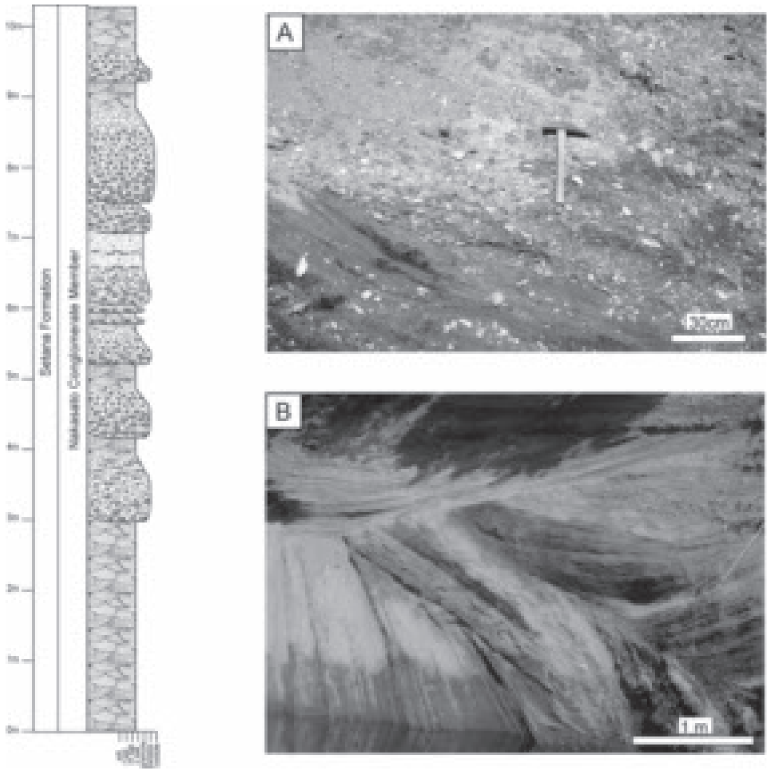

Fig. 3 Column (left) and representative lithofacies of the lower part of the Nakasato Conglomerate Member of the Nakasato Section: (A) channel-fill conglomerate; (B) cross-bedded sandstone.

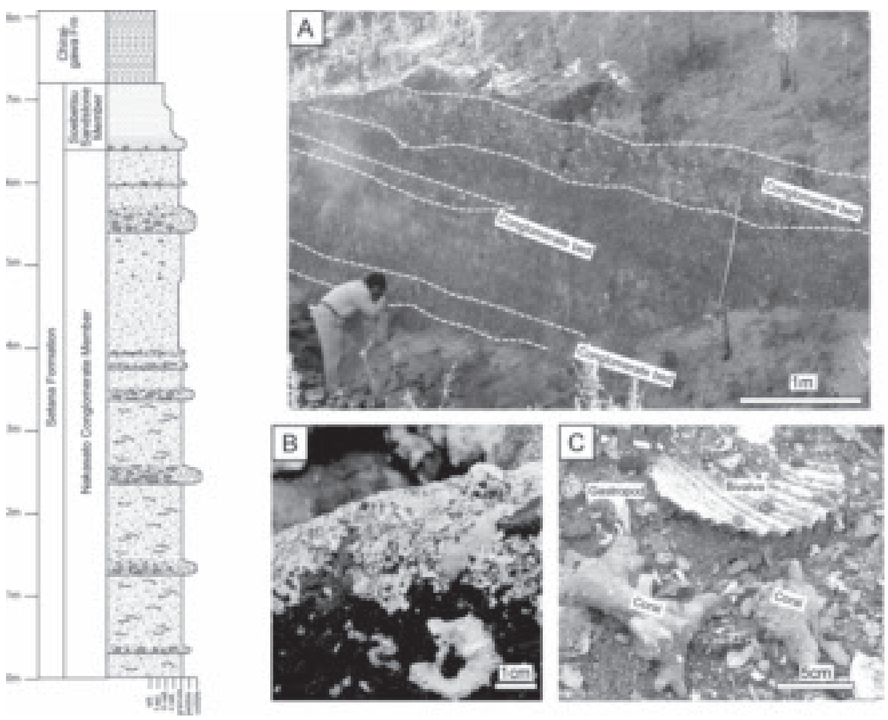

Fig. 4 Column (left) and representative lithofacies of the upper part of the Nakasato Conglomerate Member in the Utasai Section (Kokemushi Paradise Section): (A) sandstone and conglomerate beds; (B) encrusting bryozoans on the surface of a pebble; (C) gastropod, bivalve, and coral fragments in the sandstone.

ince (e.g., *Glycymeris yessoensis*, *Mizuhopecten yessoensis*, *Swiftopecten swiftii*), species characterizing the subarctic province (e.g., *Chlamys islandicus*, *Acirsa ochotensis*, *Neptunea eulimata*) occur in the lower part [4]. As for microfossils, planktonic and benthic foraminifera rarely occur.

Sedimentary environment. Based on the molluscan fauna, this member is considered to have been formed in a shoreface environment [4]. The cross-bedded sandstone and conglomerate in the lower part exhibit delta and channel systems. The inferred direction of the paleocurrent of the cross-bedded sandstone was from south to north, which indicates that detritus was supplied from south to north.

Soebetsu Sandstone Member [6]

Type section. Soebetsu River (42°41′9″N, 140°16′4″E).

Thickness. < 75 m.

Lithology. Although the Soebetsu Sandstone Member conformably overlies the Nakasato Conglomerate Member in many places, it unconformably overlies the Kuromatsunai Formation in the type section of the Soebetsu River (Fig. 5). The basal conglomerate of the Soebetsu Sandstone in the type section overlies the siltstone and coal bed of the Kuromatsunai Formation with irregular contact (Fig. 5A). Gravel elements in the basal conglomerate are subangular to subrounded and consist of siltstone derived from the underlying Kuromatsunai Formation. The sandy matrix of the basal conglomerate contains abundant bivalve fragments. This member consists mainly of strongly bioturbated very fine-grained sandstone to sandy siltstone containing abundant bivalves, gastropods, and echinoids (Fig. 5B). In the type section, this member intercalates a concentration of calcareous algae in the middle part, as well as six shell concentrations. In the northern area of the Kuromatsunai district, this member intercalates a deposit of ice-rafted debris (Fig. 5C). The Soebetsu Sandstone Member is unconformably covered by the Chiraigawa Formation.

Fossils and paleoenvironment. Most fossils in this member are autochthonous, because they are com-

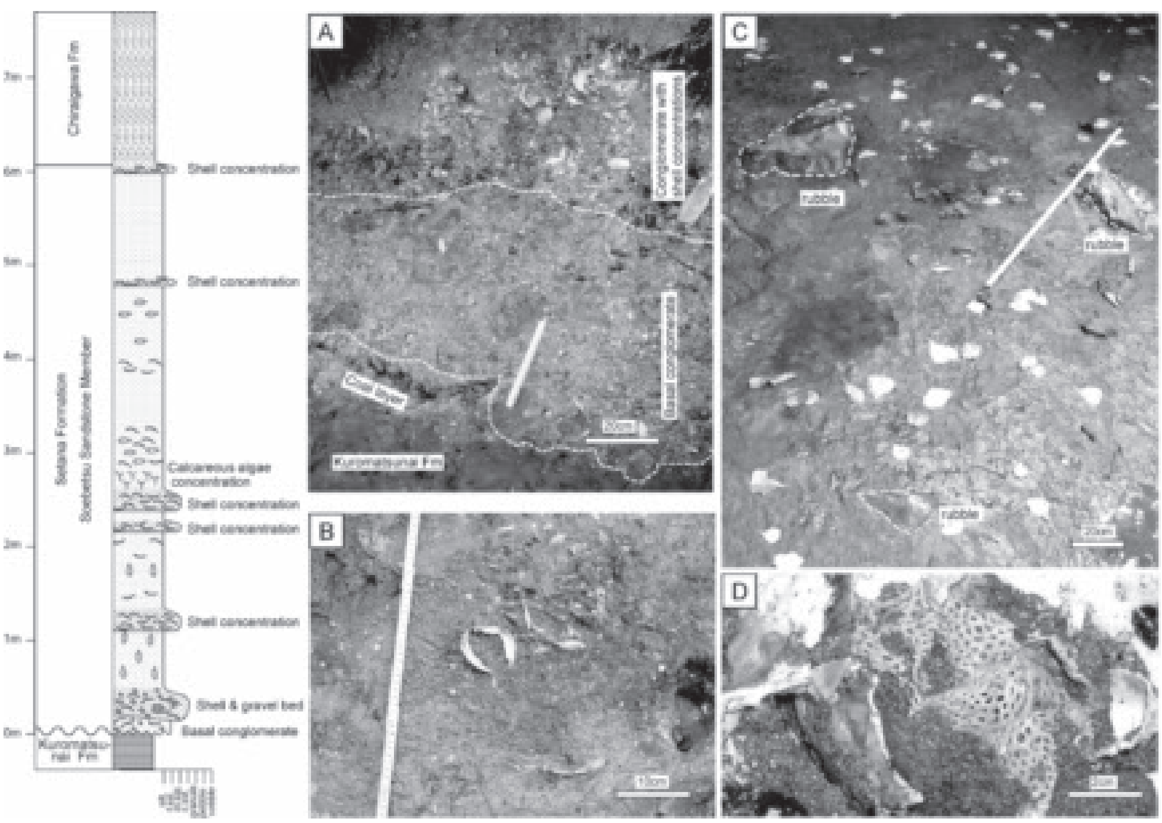

Fig. 5 Column (left) and representative lithofacies of the Soebetsu Sandstone Member in the Soebetsu Section: (A) an unconformable contact separates the Kuromatsunai Formation and the overlying Soebetsu Sandstone Member; (B) bivalves in the siltstone. (C) ice-rafted debris indicated by rubble in the siltstone matrix; (D) intact retiform colony (*Phidolopora* sp.) in the sandy siltstone matrix.

pletely preserved and bivalves are with conjoined valves (Fig. 5B). However, shell concentrations are usually shell-supported, and many of the shells are partly broken. Therefore, the mode of occurrence of these concentrations is semi-autochthonous. Although the molluscan assemblage of this member comprises species of the cool-temperate province, species characterizing the subtropical province (e.g., *Saccella sematensis*, *Rhinoclava kochi*) occur in the middle part of the member [5]. The warm-water planktonic foraminiferan *Globigerinoides ruber* occurs in the lower and middle parts of this member. These observations suggest that there were two warming episodes during the accumulation of this member, one in the lower part and another in the middle part.

Sedimentary environment. According to analyses of sedimentary facies, molluscan fossils, and benthic foraminifera, the sedimentary environment of this member was inner to outer shelf [4–6].

GEOLOGIC AGE OF THE SETANA FORMATION

According to ref. [6], the lower part of the Setana Formation (Nakasato Conglomerate Member and its equivalent members) is correlated with the overlapping interval of the *Neogloboquadrina pachyderma* (s) / *Neogloboquadrina incompta* planktonic foraminiferal zone of ref. [10] and the CN13b calcareous nannofossil zone of ref. [11] (Fig. 6). The upper part of the Setana Formation (Soebetsu Sandstone Member and its equivalent members) is correlated with the CN14a calcareous nannofossil zone of [11] (Fig. 6). K/Ar dating of one horizon of the upper part of Kuromatunai Formation gave an age of 1.89 ± 0.02 Ma, and of two horizons of the upper Setana Formation, ages of 1.0 ± 0.2 and 0.7 ± 0.2 Ma [12]. Fission-track dating of the Chiraigawa Formation showed an age of 0.4 ± 0.08 Ma. Summarizing these various data, ref [6] gave the age range of the lower part of the Setana Formation as 1.2–1.0 Ma, and the upper part as 1.0–0.6 Ma.

MODE OF BRYOZOAN OCCURRENCE IN THE SETANA FORMATION

Bryozoans occur abundantly throughout the Setana Formation. The Nakasato Conglomerate Member contains abundant bryozoans encrusting pebbles, molluscs, and corals (Fig. 4B, C). Fragments of erect bryozoan colonies are also abundant in the

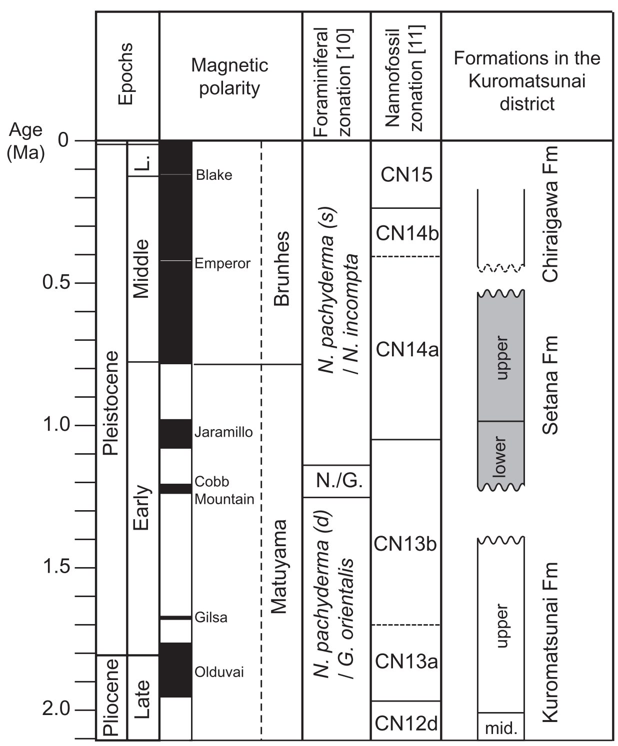

Fig. 6 Correlations of Plio-Pleistocene formations in the Kuromatsunai district. Modified from [6]. N/G: *N. pachyderma* (s)/ *G. quinqueloba* Zone.

sandstone facies. Bryozoans occur continuously throughout the Soebetsu Sandstone Member, although they are not as abundant as in the Nakasato Conglomerate Member, and include both encrusting and erect (e.g., *Microporina articulata*, *Phidolopora* sp. [Fig. 5D]) types. Encrusting species are attached to pebbles and bivalves, while many fragments of both encrusting and erect forms and occasional large, erect colonies (Fig. 5D) occur in the sandy siltstone matrix.

CONCLUDING REMARKS

While Pleistocene bryozoans have been relatively well studied in northern Japan in the vicinity of Tsugaru Strait (northern Honshu and southwestern Hokkaido), the contribution from the Setana Formation was low (13 taxa) compared to other formations in the region (e.g., Daishaka Fm., 77 taxa reported; Shibikawa Fm., 40 taxa) [3]. However, deposits of the Setana Formation in the vicinity of Kuromatsunai (SW Hokkaido) have recently been discovered to contain abundant, diverse, well-preserved bryozoan fossils, and some of these deposits such as the Utasai (Kokemushi Paradise) section are of world-class quality. This opens the way for using the Setana Fm. in the vicinity of Kuromatsunai as a model system to study, for example, the effects of climatic change on the composition and diversity of assemblages of benthic marine animals; how community-level parameters modulate these effects; responses of individual taxa to climatic change; and comparison of various proxies used to assess paleoclimate and climatic change. Our COE Kokemushi Paradise project is presently focusing on two aspects of the Pleistocene bryozoans of the Setana Formation: one is taxonomy, and the other is an integrated approach to dating and paleoclimate reconstruction by means of MART analyses [13], magnetostratigraphic and rockmagnetic investigations [14], and analyses of foraminiferal assemblages and oxygen isotope ratios [15].

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