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# Plio-/Pleistocene Temperate carbonates of the Zukawa Formation, Toyama Prefecture and its comparison with Tropical carbonates

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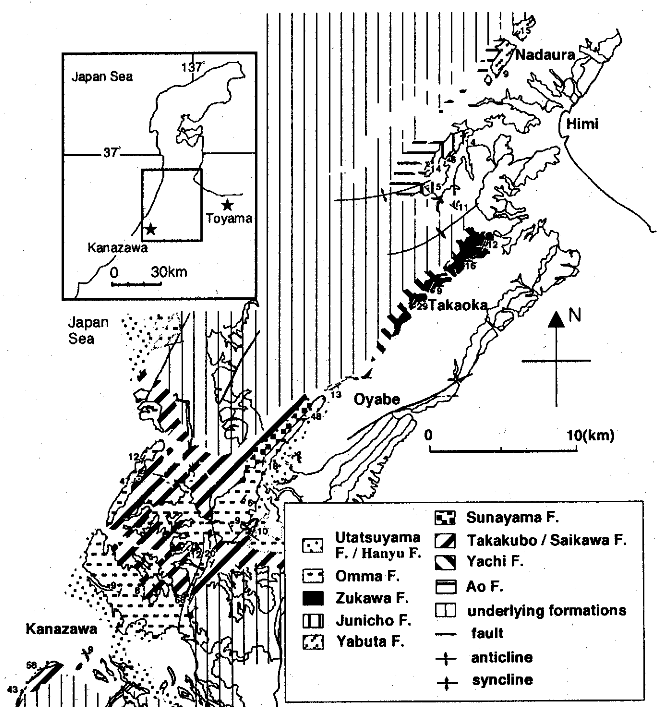
**Abstract - Temperate carbonates (or Cool-water carbonates) of the Zukawa Formation consist of calcareous red algae, bryozoans, benthic foraminifers, bivalve molluscs, barnacles, ostracods and surpulids. These associations correspond to the foramol association. Sedimentary facies of the Zukawa Formation divide into three facies: Facies A, B and C. Sedimentary environments of these deposits are considered to be upper shoreface to lower offshore at the depth between 0 and 100m. Fluctuation of the paleoenvironments indicates that deeping upward sequence occurred twice in the Formation. Stratigraphic position of the Zukawa Formation correlates to late Pliocene to early Pleistocene on the basis of calcareous nannoplankton. The Upper part of the Formation gradually increase production of carbonates during late Pliocene and early Pleistocene. This incident resembles late Pliocene and early Pleistocene sediments in Ryukyus.**

## I. Introduction

Carbonates mainly distribute in the tropical area such as atoll reef, barrier reef and fringing reef. On the other hand, carbonates are generally rare in the temperate area. Recently, several studies reported temperate carbonates in temperate areas (e.g. Scottland[1], Ireland[2], New Zealand[3] and Australia[4, 5, 6]). These studies gradually revealed sedimentary facies and biofacies of recent temperate carbonates. Biofacies of the temperate carbonates is low in diversity than that of tropical carbonates. Also, several studies revealed the sedimentation of temperate carbonates [6, 7]. In Japan, temperate carbonates are rare through geologic time. Recent study reported Miocene temperate carbonates of the Tanosawa Formation, northern part of Tohoku[8]. Sedimentological and paleontological analyses of temperate carbonates have just started over Japan. The Plio-/Pleistocene calcareous sandstone of the Zukawa Formation is one of the temperate carbonates in geologic time. Previous study of the Zukawa Formation gave little knowledge on the temperate carbonates. These deposits will provide significant information on the paleoenvironments around Hokuriku in late Plicene and early Pleistocene. This report aims to (1) introduce temperate carbonates of the Zukawa Formation, (2) compare them with Pleistocene tropical carbonates in Japan (Ryukyu Group) and (3) estimate sedimentary environments and process.

## II. Geologic outline

The Zukawa Formation of the Himi Group mainly consists of the late Pliocene and the early Pleistocene calcareous sandstone, sandstone and siltstone in the western part of Toyoma Prefecture, Central Japan (Fig.1). It is up to 170m thick.



(modified from Hasegawa, 1979)

Fig.1. Geological map of the part of Hokuriku district.

The Formation may correlate to the Junicho Formation and the lower to middle part of the Omma Formation (Fig. 2) [9]. However, previous studies are rare biostratigraphic and magnetostratigraphic data of the Zukawa Formation. Previous studies gave stratigraphic position of the Zukawa Formation after compared the data with biostratigraphic, magnetostratigraphic and tephronstratigraphic data of the Omma and the Junicho Formations [10]. Calcareous nannoplankton biozones are corresponded to the datum levels No. 5 to 12 in the Omma Formation and datum levels No.11 to 12 in the Junicho Formation [10]. Paleomagnetic study indicates Matuyama chron with Olduvai subchron [9].

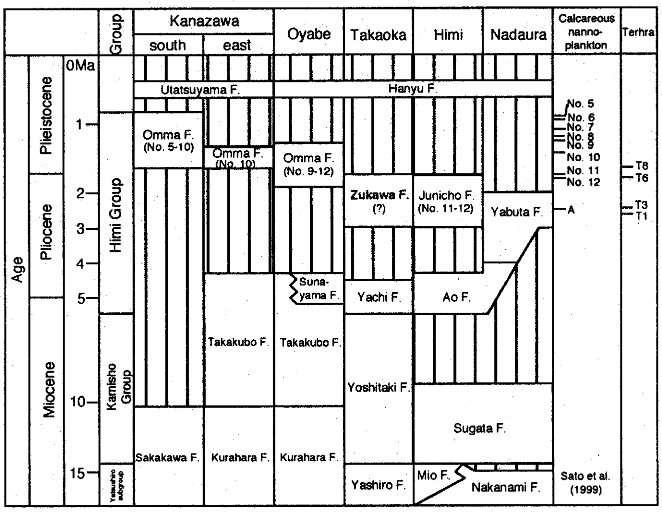



Fig. 2. Stratigraphic relationship of the strata in the Hokuriku distrinct .(modified from Hasegawa, 1979;Arai et al., 2001)

## III. Temperate Carbonate of the Zukawa Formation

Characteristics of temperate carbonates are represented by non-reef structures, low rates of sedimentation, low diversity, low equitability and non-component of non-skeletal grain (ooid and peloid). Calcareous sediments of the Zukawa Formation have low diversity of organisms and they consist of bryozoans, calcareous red algae, benthic foraminifers, bivalve molluscs, echinoiderms, barnacles, ostacods and surpulids. This report divides the sediments into three facies on the basis of sedimentary facies and biofacies as an example, taken in the eastern Zukawa quarry (Fig. 3).

### *A Facies A*

This facies consists of very fine- and fine calcareous sandstones, sandy limestone and the limestone with burrows. Skeletal grains are mainly composed of bryozoans, benthic foraminifers, echinoiderms, ostracods and bivalve molluscs. Facies A is divided into two sub facies with sedimentary structure. A-1 contains coarse sand layer. A-2 contains wavy bedding. Burrows are identified as *Rosselia.*

### *B Facies B*

This facies consists of fine and medium calcareous sandstones and sandy limestone with trough cross bedding and some burrows. Skeletal grains are mainly composed of bryozoans, benthic foraminifers, echinoiderms, calcareous red algae and bivalve molluscs. Burrows are *Thalassinoides*.

### C *Facies C*

This facies consists of fine calcareous sandstone with bioturbation and well-rounded pebbles. Pebbles are encrusted by calcareous red algae, bryozoans, barnacles, bivalve molluscs, gastropod molluscs and serpulids.

| *Facies* | *Sub-facies* | *Lithology* | *Sedimentary structures* | *Skeletal grains* | *Environments* |
|---|---|---|---|---|---|
| A | A-1 | very fine to fine calc. ss. sandy ls. ls. | grading | bryozoans benthic foraminifers echinoderms bivalve molluscs | upper to lower offshore |
| | A-2 | very fine to fine calc. ss. sandy ls. | wavy bedding burrows | | |
| B | | fine to medium calc. ss. sandy ls. | cross stratified | bryozoans benthic foraminifers echinoderms bivalve molluscs calcareous red algae | lower shoreface |
| C | | fine calc. ss. with pebble | bioturbated | calcareous red algae bryozoans benthic foraminifers echinoderms bivalve molluscs gastropod molluscs serpulids | upper shoreface |

Fig. 3. Sedimentary facies of the Zukawa Formation

Skeletal grains are mainly composed of bryozoans, benthic foraminifers, echinoiderms, bivalve molluscs, red algae and barnacles. All skeletal grains are mainly composed of high Mg calcite or low Mg calcite.

In the eastern Zukawa quarry, the Formation of ca.30m thick divides into two units; Unit I and II. The thickness of the Unit I is ca.15m, and the facies change upward from facies C of 12.5m thick, facies A-2 of 0.5m thick to facies A-1 of 2.5m. Unit II is at least 17m in thickness and the facies changes upwards from facies C of 3 m thick, facies B of 10m thick, facies A-1 of 2.5m thick to facies A-2 of minimum 1.5m thick.

## IV. Sedimentary environments

Paleoenvironments of the sedimentary facies are considered to be upper shoreface to upper offshore. Facies A is offshore deposits under low energy position. The A-1 is upper to lower offshore with sporadic turbidites and the A-2 is offshore with sporadic tempestites. Additionally, *Rosselia* is usually found from the lower shoreface to the offshore [11]. Facies B is the lower shoreface above fair-weather wave base and in high energy conditions. *Thalassinoides* is found from tidal flat to shoreface [11]. Facies C is upper shoreface with bioturbation. Facies C is near rocky mound because its facies contains pebbles with benthic biofacies such as encrusting calcareous red algae and bryozoans. In the eastern Zukawa quarry, two units indicate deeping upward sequences.

Previous study reported five sedimentary facies from the Zukawa Formation [12]. Facies were divided into Bathyal, Lower shallow marine, Upper shallow marine, Littoral, Marginal marine. Three facies in this report relate to upper shallow marine and lower shallow marine facies. Skeletal organisms of the Zukawa Formation correspond to the foramol association [13](Table 1). This association mainly contains bryozoans, benthic foraminifers and bivalve molluscs associated with calcareous red algae and indicate under 0 to 15° C. This association is typical to the temperate carbonates. Paleodepth of biofacies with calcareous red algae was probably less than 60 to 100m because calcareous red algae distribute under photic zone [14,15]. Additionally, previous study reported the temperature and the salinity around the recent Toyoma Bay and the eastern part of the Noto Peninsula [16]. The Temperatures are 22 to 28°C under 0 to 20m and are 10 to 20°C under 50 to 100m. On the other hand, salinity is 33 to 34‰ under 0 to 20m and is 34.4 to 34.5‰ under 50 to 100m. Recent marine setting around the Noto Peninsula and the Toyama Bay correspond to foramol association (Fig. 4). This association enough to deposit under conditions around the recent Noto Peninsula and Toyama Bay. Also, previous study around the recent Noto Peninsula reported hermatypic and ahermatypic corals [17]. Skeletal organisms at rocky mound are mainly calcareous red algae, barnacles, surpulids and bryozoans. Consequently, even the Zukawa Formation have no ahermatypic and hermatypic corals, paleo-marine setting during late Pliocene and early Pleistocene resemble the recent setting around the Noto Peninsula and the Toyama Bay.

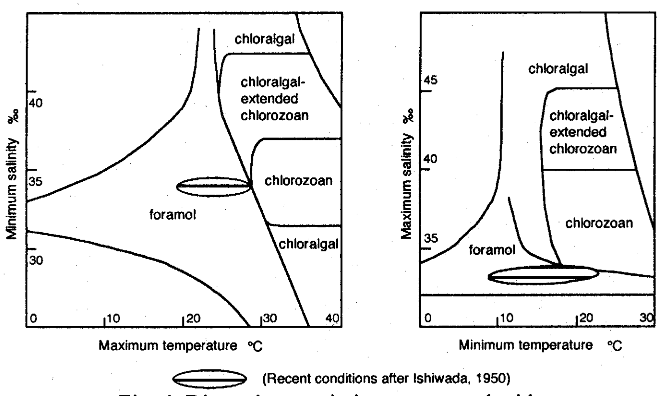



Fig. 4. Biogenic associations compared with recent Noto Peninsula and Toyama Bay.

## V. Age assignment

This report tries to analyze biostratigraphy of calcareous nannoplankton in the Formation. Calcareous nannoplankton, *Calcidiscus macintyrei* and *Helicosphaera sellii* were found from Ebizaka. However, these calcareous nannoplanktons are no useful for biostratigraphic data. The Zukawa Formation contains *Gephyrocapsa caribbeanica. G. caribbeanica* which were found from the upper part of the Zukawa Formation [12]. The Zukawa Formation contains no *Gephyrocapsa* (large). These association correlates to datum No. 12 [18]. Consequently, the upper part of Zukawa Formation correlates to 1.76 to 1.45 Ma. The stratigraphic position correlates to the middle and lower part of the Omma Formation in Kanazawa and the upper part of the Junicho Formation. The middle part of the Zukawa Formation probably correlates to Plio- / Pleistocene boundary.

## VI. Comparison of temperate Zukawa carbonates with Plio- and Pleistocene tropical carbonates

Biogenic diversity are high in the Tropical carbonates. These typical biogenic grains are hermatypic corals, calcareous green algae, calcareous red algae, benthic foraminifers, mollusc and echinoiderms (Table 1). These consist of aragonite, high Mg calcite and low Mg calcite. Skeletal grains of tropical carbonates relates to Chlorozoan and Chloralgal association [13]. These associations distribute under 15 to 30° C. The Foramol associtaion distributes at continental shelf (<150m deeper) in the tropical area.

Table 1
Comparison with tropical and temperate carbonates

| Environmental and facies parameters | Tropical carbonates | Temperate carbonates |
|---|---|---|
| *Skeletal carbonate components* | | |
| Flora | calcareous green algae | calcareous red algae |
| | calcareous red algae | cocolithophorids |
| Fauna | hermatypic corals | bryozoans |
| | benthic foraminifers | bivalves molluscs |
| | molluscs | bethic foraminifers |
| | | barnacles |
| | | echinoderms |
| | | serpulids |
| | | brachiopods |
| *Skeletal attributes* | | |
| Rates of production | high | low to high |
| Diversity | high | mainly lower |
| Equitability | low | mainly higher |
| Carbonate mineralogy | aragonite | low- and /or high-Mg calcite |
| Skeletal grain associations | chlorozoan | foramol |
| | chloralgal | bryomol |

Skeletal grains of the late Pliocene and the early Pleistocene Chinen Formation in Okinawa Island resemble the foramol association. This facies laterally change into coral reef facies of reddish-colored limestone [19]. Coral reef facies contains hermatypic corals, calcareous red algae, calcareous green algae (eg. *Halimeda*) and foraminifers and correspond to chlorozoan association. The stratigraphic position of the Chinen Formation is located between the Pliocene Shimajiri Group (siliciclastic siltstone, sandstone of forearc deposits) and the Pleistocene Ryukyu Group (reef limestone). Increasing of production of carbonates in Ryukyu Islands during the late Pliocene and the early

Pleistocene probably reflect the warm currents pass through Ryukyu Islands because planula of hermatypic corals are drifted by warm currents from low latitudes. These incidents may be related to the formation of the pass-way of recent warm currents around Japan. Development of tropical carbonates in Ryukyus gradually distributes since late Plio- and early Pleistocene [20].

The facies of the tropical carbonates has generalized sequence: coral facies (Coral limestone facies) to insular shelf facies (Rhodolith limestone facies, Large foraminiferal limestone facies and *Halimeda* limestone facies) or coral reef facies to insular shelf facies, overlain by coral reef facies. These generalized sequences relate to Quaternary glacio- sea-level changes and are called Unit [20, 21]. A Unit corresponds to high-frequencey sequence (fourth-order cycle). A Unit boundary corresponds to the sequence boundary.

## VII. Increasing of Plio- amd Pleistocene temperate carbonates

Early Pleistocene Omma Formation in Hokuriku shows the cyclic changes of sedimantary facies and molluscan assemblages [22, 23, 24, 25, 26]. The changes relate to the eustatic sea-level changes and molluscan assemblages change from cold to warm waters. The Junicho Formation contains sediments with calcareous material [27]. The Junicho Formation has formed under glacio-eustatic sea-level change during late Pliocene and early Plesitocene. In the Hokuriku district, calcareous materials increased in this duration. These incidents correspond to the timing of wide-spreading tropical carbonates. Late Pliocene and early Pleistocene cool-water carbonate in the Hokuriku area may relate to the increase of warm currents because previous study considered that there was a mixing zone with collision of warm currents and cold currents in western Toyama [28]. These incidents resemble the setting of temperate carbonates in Great Australia Bight, southern coast of Australia [6].

## VIII. Magnitude of eustatic sae level change

One of the factors to boost of temperate carbonates is the flux of warm currents with eustatic sea-level change. Oxygen isotope fluctuation since 2Ma can be divided into two group in terms of length and oscillation: 2 to 1Ma, and 1 to 0Ma with transitional duration at 1 to 0.8Ma [29]. Oxygen isotopic fluctuation relates to change of salinity and temperature. The curve of late Pliocene and early Pleistocene indicates length at ca 40ka. and oscillation to ca. 1‰. Lower Pleistocene tropical carbonates response to relative sea-level change in Ryukyus [30]. Magnitude of sea level changes indicates ca. 30m in Ryukyus during early Pleistocene on the basis of sequence stratigraphic analysis and fossil hermatypic coral assemblage. The sea level curve is characterized by high frequency and lower-amplitude cycles during early Pleistocene. The lower Pleistocene Omma Formation responses to glacio- and eustatic sea level change [22, 23, 24, 25, 26]. Magnitude of glacio- and eustatic sea level indicates ca. 50m on the basis of molluscan assemblage [22]. Also, late Pliocene and early Pleisotocene Junicho Formation has formed under glacio-eustatic sea-level changes [27]. Its fluctuation ranges over 30m. In this report, the fluctuation of the Zukawa Formation can be estimated as ca. 30m on the basis of sedimentary facies. These sea-level changes resemble that of Ryukyus during early Pleistocene. Although previous study of the Zukawa Formation had not been analyzed from the sequence stratigraphy, it may have formed under the magnitude of glacio-eustatic sea-level change during late Pliocene and early Pleistocene.

## VIII. Summary and Conclusion

Temperate carbonates of the Zukawa Formation consist of calcareous red algae, bryozoans, benthic foraminifers, bivalve molluscs, barnacles, ostracods and surpulids. These associations correspond to foramol association under 0 to 15° C. Sedimentary facies of the Zukawa Formation divide into three facies in the eastern Zukawa quarry. These facies relate to the upper shallow marine and lower shallow marine facies based on the previous studies. Sedimentary environments of these deposits are supposed to be upper shoreface to lower offshore at 0 to 100m of photic zone. In the eastern Zukawa quarry, fluctuation of paleoenvironments indicates two series of deeping upward sequence. Stratigraphic position of the Zukawa Formation correlates to late Pliocene to early Pleistocene on the basis of calcareous nannoplankton biozone. In the Ryukyus, the production of carbonate increases during late Pliocene and early Pleistocene. These incidents may have been triggered by the pass-way of warm currents through Japan. Increasing production of the Zukawa carbonates through late Pliocene and early Pleistocene correspond to the timing of wide-spreading tropiocal carbonates around Ryukyus.

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