WANO FORMATION (EOCENE) IN AMAMI-OSHIMA, RYUKYU ISLANDS, JAPAN

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(Received September 10, 1968)

INTRODUCTION

Amami-oshima is situated in the northeastern part of the Ryukyu Islands stretching from the southern end of Kyushu to the northeast of Taiwan. Several reports have been published on the geology of this island (YOSHIWARA (=TOKUNAGA), 1901; ISHIKAWA, 1910; HANZAWA, 1932; and HATAE *et al.*, 1959). The former three described that the island consists of only Paleozoic rocks which are veneered by Quaternary sediments. HATAE *et al.* (1959) showed that the basement complex of Amami-oshima consists of six formations; from northwestern side of the island, the Paleozoic Naon, Odana, Shinmura, Naze, and Ogachi formations, and the Mesozoic(?) Wano formation. The last formation is primarily composed of thin-bedded alternation of sandstone and shale, and crops out in the eastern half of the Kasari Peninsula.

KONISHI (1963, 1965) has discussed on the zonal distribution of the basement complex in the Ryukyu Islands on the basis of lithological, paleontological and tectonic evidences, and grouped the basement complex into the following six belts; Koshikijima, Ishigaki, Motobu, Kunigami, Shimajiri, and Kumage. The Motobu, Kunigami, and Shimajiri belts were respectively compared with the Chichibu terrain, the northern belt, and the southern belt of the Shimanto terrain in Southwest Japan. According to this scheme, the Wano formation in the Kasari Peninsula is to crop out in the Shimajiri belt.

The purpose of this study is to elucidate areal geology of the Kasari Peninsula, and the correlation between the basement rocks in the peninsula and the rocks of the Shimanto terrain in South Kyushu with special emphasis on the Wano formation. An attempt was also made to study the Wano formation from the sedimentological point of view**.

The writer wishes to express his hearty thanks to Professor Kenji Konishi of Kanazawa University for his valuable advice throughout the present study, and is also greatly indebted to other staff members of the

Department of Earth Sciences at the same university. He expresses his thanks to Dr. Shoshiro Hanzawa, professor emeritus of Tohoku University, for identification of foraminifers from the Wano formation. The identification of other fossils from the Wano formation was kindly given by Drs. Hidekuni Matsuo of Kanazawa University (land plants), Akira Morishita of Nagoya University (echinoids) and Atsuyuki Mizuno of the Geological Survey of Japan (molluscs). Finally, the writer would like to thank to Professor Toshio Kimura of the University of Tokyo for his keen interest in this study.

OUTLINE OF GEOLOGY

1. General

The stratigraphical sequence of the sedimentary rocks cropping out at the Kasari Peninsula consists of***; in descending order,

Recent

Fluviatile deposits, Dune sand, Beach rock
Coral reef
Ushuku sand
Tomori dune sand

Pleistocene

Kasari limestone, Setta gravel, Taira clay

Eocene

Wano formation

- 8) member; shale
- 7) member; thin-bedded alternation of sandstone and shale
- 6) member; sandstone
- 5) member; thin-bedded alternation of sandstone and shale
- 4) member; sandstone
- 3) member; shale
- 2) member; conglomerate
- 1) member; sandstone

Late Mesozoic

*** All the formational names except the Wano formation are newly proposed through this paper. The beds designated herewith as the Akakina formation were lumped together as the Ogachi (=Ohgachi of some authors) formation by HATAE *et al.* (1959); the present writer segregated the Ogachi formation in the Kasari Peninsula from that of the other part of the island, and newly named as the Akakina formation because of the lithologic differences.

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** Some parts of this paper were presented to the Graduate School of Kanazawa University as the partial fulfillment of the M. Sc. degree (ISHIDA, 1967; ISHIDA *et al.*, 1967).

COLUMNAR SECTIONS OF THE WANO FORMATION

CROSS SECTION

EXPLANATION

Quaternary
Tertiary { Late Eocene Granite
Eocene Wano formation
Cretaceous(?) Akakina formation

8) member ; shale
7) member ; thin-bedded alternation of sandstone and shale
6) member ; sandstone
5) member ; thin-bedded alternation of sandstone and shale
4) member ; sandstone
3) member ; shale
2) member ; conglomerate
1) member ; sandstone
7) member ; alternation of sandstone and shale
6) member ; alternation of sandstone and shale
5) member ; shale
4) member ; alternation of sandstone and shale
3) member ; slate
2) member ; greenstone
1) member ; phyllite

Gr
W8
W7
W6
W5
W4
W3
W2
W1
A7
A6
A5
A4
A3
A2
A1

— — — — — Contact
— — — — — Fault
— — — — — Anticline (overturned)
— — — — — Syncline (overturned)
— 30 — 30 — Strike and dip of beds

Dashed where approximately located or inferred;
dotted where concealed by the Quaternary sediments

Fig. 1. Geologic map of the Kasari Peninsula in Amami-oshima (excluding the Quaternary marine sediments), and columnar sections of the Wano formation.

Akakina formation

- 7) member; alternation of sandstone and shale
- 6) member; alternation of sandstone and shale
- 5) member; shale
- 4) member; alternation of sandstone and shale
- 3) member; slate
- 2) member; greenstone
- 1) member; phyllite

The Wano formation develops on the eastern side of the peninsula, and is bounded by the Akakina formation on both western and eastern sides. It makes up an overturned syncline accompanied with minor folds of which the axes strike NNE-SSW. All the beds of these two formations have strike of NNE-SSW and inclined steeply to NWW, and the faults separating the formations are characterized with the prominent fracture belts 20 to 200 m wide. The Akakina formation has many complex folding and faulting structures, and most beds cropping out on the western side of the peninsula are inverted. The Akakina formation consists chiefly of muddy rocks of which some parts, especially lower parts of the formation, are regionally metamorphosed changing into phyllite, whereas the Wano formation consists mainly of sandstone and thin-bedded alternation of sandstone and shale.

Among the Quaternary beds of limestone, terrace deposits, dune sand, and others which unconformably overlie both the Akakina and Wano formations, the second is best developed as the raised coastal terrace.

Granite occurs as narrow and elongate intrusive body in the Akakina formation, being concordant to the strike of the formation.

2. Akakina formation

The Akakina formation is mainly developed in the western area and partly along the eastern coast of the Kasari Peninsula. This is composed of shale, slate, phyllite, sandstone, thin-bedded alternation of sandstone and shale, greenstone, and tuff, and lithologically divided into seven members. The type locality of this formation is along the route from Gamo-zaki, passing through Akakina, to the east of Akakina. The Akakina formation amounts to about 5,700 m in thickness. However, the details are not clear because of its structural complications, its upper limit being faulted and the lower one concealed in the sea.

Shale, slate, and phyllite are grey to black, and sometimes contain many ellipsoidal pebbles and cobbles of sandstone as well as nodules of siliceous shale and muddy limestone. Sandstone is grey to white grey and coarse- or medium-grained, and rarely bears many shale rubbles a few centimetre in diameter, which merges into conglomerate. Thin-bedded alternation of sandstone and shale of the Akakina formation, of which the individual layer ranges from 5

to 20 cm in thickness, is severely deformed. These beds of sandstone and thin-bedded alternation are especially predominant in the upper horizons of the Akakina formation. Three beds of greenstone, found within the lower and upper parts of the greenstone member and the bottom of the top member, are good key-beds, each thickness of which varies from 10 to 70 m. Their rocks are meta-basalt, and are accompanied by the pillow structures at Kaminoko, Kujirahama, Uttabaru, and the southern coast of Gamo-zaki. In most areas, the several beds of white grey tuff and/or reddish brown shale, of which each bed is about 1 m in thickness, are interbedded conformably in the phyllite associated with meta-basalt.

3. Wano formation

The Wano formation is developing in the eastern area between Setta and Suno, and in northern regions of Kasari and Yo. Four columnar sections were obtained along the routes of 1) the western coast of Setta, the type locality of this formation, 2) Wano—Setta, 3) Akakina—Wano, and 4) Manya—Yodeyama, as shown in Text-figure 1. The type locality stays on the western limb of the synclinal fold, where the stratigraphical thickness of the formation is about 800 m.

This formation which consists of sandstone, thin-bedded alternation of sandstone and shale, shale, and conglomerate is classified lithologically into 8 members as shown in the columnar sections. It is slightly different in the rock-facies between the lower three members and the others, and they show two sedimentary megacycles. Furthermore, two sedimentary cycles changing from sandstone to thin-bedded alternation and shale are observable in the upper five members. All the contacts between these members are conformable, and there is a tendency to decrease the grain size of sediments upwards throughout these members.

The sandstone member consists of alternations of pale grey sandstone layers from 3 m to 20 cm thick and black shale layers a few centimetre thick, and at the bottom of sandstone layers many current marks and load moulds are observed. The sandstone of the Wano formation is different from that of the Akakina formation, with respect to that the former is well-sorted and fine-grained, contains many grains of muscovite with an appreciable amount of chlorite and some ichnofossils, and preserves well-developed parallel lamination.

The thin-bedded alternation sequence which occupies a half of the Wano formation in thickness consists of thin (2–20 cm) layers of shale and sandstone. The sandstone in 5) and 7) members (thin-bedded alternation) is lithologically similar to the one in 4) and 6) members (sandstone). Various current marks such as flute-, groove-, and prod-moulds, and load moulds are

found at the bottom of sandstone layers, which are useful to decide the upper or lower surface of the otherwise lithologically monotonous layers. They are also useful to learn the current direction, with the additional analysis of the sedimentary structures as cross lamination and flame structure. Many ichnofossils are seen on both the upper and lower surfaces of the sandstone layer, although apparently more common on the upper surface.

The shale of 3) and 8) members is black to dark grey and clayey, but the former has in addition a bed of silty shale at Okari-yama due north of Setta, Manya, and 1 km west of Tomori. Within this silty shale and the upper clayey shale at the first locality, many nodules 5 to 30 cm in diameter are met with, which contain fossils of gastropod, pelecypod, echninoid, and cones and leaves of land plants.

The conglomerate is generally 10 to 30 m in thickness, but attains to the thickest being 80 m at the type locality of the Wano formation. It consists of many stratified and graded beds, with a few exceptions of some beds without graded bedding, in which the cobbles are gathered to form lentils. The diameter of gravels ranges from 5 to 20 cm, and tends to decrease rapidly to 1 cm or so northwards, where the clayey matrix in the conglomerate increases. The gravels consist of sandstone, shale, chert, limestone, granite, dacite, quartzite, quartz-porphyry, gneiss, and schist.

4. Quaternary sediments

In Amami-oshima, the *Kasari limestone* hitherto dealt as the Riukiu limestone crops out only at Tsuchihama, Kasari, and Yo, and seems to exceed 10 m in maximum thickness. It is composed of many grains of coral, foraminifer, bryozoa, and calcareous algae in coarse sand-size, cemented hard with calcite, whereas the basal part 1 to 2 m thick of the limestone unit contains a lot of well-rounded cobbles derived from the underlying formations, and many reef-building corals.

The *Setta gravel* about 1 m thick is distributed on the terrace which occupies the altitude from 10 m to 50 m and mainly develops on the east side of the peninsula. It is composed of brown sands and well-rounded to subangular pebbles as well as cobbles and boulders of fine-grained sandstone, shale, granite and chert derived from underlying rocks nearby.

The *Taira clay* is developed only at three areas, Kawauchi, Taira, and between Okari-yama and Yodeyama, to fill the valleys stretching in the NW-SE direction. It consists of angular to subangular pebbles of shale and sandstone, dark grey silt with many fragments of plants, greyish white tuff, and reddish brown clay bearing roots. The first lithology is predominant at the lower part of this formation. The thickness of the

Taira clay is about 5 m. The Taira clay seems to be lake- or marsh-sediments formed at some time during the sedimentation of the Setta gravel as indicated from the field evidences, and they may be contemporaneous with the Kasari limestone.

The *Tomori dune sand* is developed along the eastern margins of widely developed terraces from Setta to Tomori where the Kasari limestone does not develop. It seems to exceed 15 m in thickness at the thickest part. The dune consists of somewhat consolidated sand-grains of foraminiferal tests and other calcareous material, with remarkable cross lamination and many remains of land snail.

The *Ushuku sand* is consisting of brown sand with many foraminiferal tests, corals, shells, and rarely pumices, lying on the terrace from 10 to 30 m in height above sea level. It has regular thickness about 30 cm, and covers the Setta gravel, Tomori dune sand, and Kasari limestone with a flat eroded plane.

The coral reef surrounding the peninsula is 500 m broad in general, and the flat surface of it is situated between the high and low tides. At the coast near Tomori, there exists a boulder of pebble conglomerate, which derived probably from the Wano formation, perched on pedestal remnant 150 to 200 cm higher than the present reef surface. Judging from this mushroom stack, it is presumed that the previous reef flat was at least 2 m higher than the present one (KONISHI, 1964). A Pa^{231} dating was carried on a coral taken from the top of pedestal remnant, and the date was preliminarily obtained to be $(4.0 \pm 0.2) \times 10^3$ years (OMORI, MS). More dates are being measured for similar samples.

In addition to these sediments mentioned above, the sporadical distribution of fluviatile deposits, dune sand and beach rock has been recognized.

5. Granite

The granite cropping out longitudinally from Akakina to Myogan-zaki belongs to medium-grained biotite-granite which consists primarily of biotite, plagioclase, potash-feldspar, and quartz. The contact between the granite and the Akakina formation shows generally a shattering zone about 50 m wide, and the thermal effect is scarcely recognized.

According to SHIBATA and NOZAWA (1966), nearly half of the granite mass seems to be mylonitized to various degrees, and the strongly mylonitized part is turned to be green. The K-Ar dating carried out by these authors for biotite separated from the granite gave $(49 \pm 6) \times 10^6$ years (Late Eocene).

SEDIMENTOLOGICAL DATA OF THE WANO FORMATION

1. Sole markings*

The current marks such as flute moulds, bounce moulds, groove moulds, prod moulds, and other undetermined scour marks, as well as the deformational marks such as load moulds are observable at the bottoms of sandstone layers in the sandstone members and the thin-bedded alternation members of the Wano formation. Flute moulds and load moulds are predominant in the sandstone members, while small flute moulds, bounce moulds, and micro-groove moulds are common in the thin-bedded alternation members.

The flute mould in the sandstone members is almost always 50 cm in length and 20 cm in width with comparatively flat top, but the one in the thin-bedded alternation members is smaller, a few centimetre in length. Most of the groove moulds found in the thin-bedded alternation members are micro-groove moulds 2 mm in width, though some marks reach to 1 cm in width. Prod- and bounce-moulds are extremely rare, and both are about 3 cm in length. Besides these current marks, there are many marks of undetermined nature under most of the sandstone layers in the thin-bedded alternation members. They seem to represent a shallow "scour mark" weakly developed.

These sole markings often coexist together on the bottoms of sandstone layers in the Wano formation. Various authors described the association of markings and their order of formation in turbidites (e.g., Hsu, 1959; HOPKINS, 1964; DZULYNSKI and WALTON, 1965). These seem to be disagreement as to which was formed earlier between tool- and scour-marks.

Although, in the Wano formation, flute moulds associated with large groove moulds have not been found, it was observed on some layers that the flute moulds being in parallel with micro-groove moulds postdate the formation of the micro-groove moulds. On the other cases, both groove and micro-groove moulds are seen overlapping each other in oblique at an angle of 30°. The ridges of large groove moulds partly modified to be low, where micro-groove moulds are carved. Then it is concluded that groove moulds impressed earlier than flute moulds occur, and large groove moulds were formed earlier than micro-groove moulds in this case of the Wano formation. Such an order agrees well with Hopkins's opinion (1964). The association of sole markings may be the result of reunited currents or different current-forces in one current.

2. Internal structures

Various types of internal structures such as graded bedding, lamination and flame structure were observed

on polished cross sections of the sandstone layers in 5) and 7) members (thin-bedded alternation), which were cut parallel to the long axes of the sole markings. A complete sequence of the sandstone layer seems to be divided into several intervals as noted by BOUMA (1962), although strict application of the prototype consisting of five intervals is impractical. In the Wano formation the following three types of sequences consisting only one or few intervals are predominantly observable; 1) a set of graded, parallel-laminated, and cross-laminated intervals, 2) that of poorly graded interval plus parallel-laminated interval, and 3) only parallel-laminated interval. In the cases of the former two, positive grading is exceptional and faint, and 1) poor grading, 2) multiple grading, and 3) pen-symmetrical grading (termed by KSIAZKIEWICZ, 1954; DZULYNSKI *et al.*, 1965) are abundant (see Text-figure 2).

3. Current direction

The data of current direction were obtained from the observation of current marks and cross lamination in the sandstone and thin-bedded alternation members of the Wano formation exposed along the road-cuttings in southeastern region of the peninsula. In the field, it was tried to determine one direction per a layer and to measure it in as many layers as possible at one locality. When there were sole marks lying obliquely each other on a layer, as mentioned in the section 1, the most predominant direction was taken as the representative for the layer. Moreover, the direction of some marks such as tool marks showing only axis of current was determined with the aid of cross lamination in cross

Fig. 2. Sedimentation types found in sandstone layers.

A : Predominant sequences. B : Three types of grading.

* Refer to the works of KUENEN (1953), BOUMA and BROUWER (1964), PETTIJOHN and POTTER (1964), and SANDERS (1965) for methodology of the analysis of these sedimentary structures.

section.

Though the number of both localities and layers observed with the above method is limited, the current direction at one locality tends to vary within a limited range, depending on layer, as shown in Text-figure 3. These directions are corrected only by rotating the marks to its horizontal position around the strike of the layer, though the correction due to the plunge of folding axis must be done in order to obtain initial direction more precisely.

Text-figure 4 shows the mean current direction at each measured locality. They are almost northwestward on the eastern limb of syncline, whereas, except a current direction showing SW at one locality (northwest of Setta), only the axes of currents trending to NE-SW

are obtained on the other limb.

Then, if the current direction at one locality on the western limb be ignored as an exception, two alternatives may be considered; 1) the northeastward current-direction on the western limb with the axis of syncline plunging towards NNE, or 2) the southwestward one with the axis of syncline plunging towards SSW. Actually, however, the axis of syncline in the Wano formation is plunged southward, and, on the other hand, both the thickness of 4) and 6) members (sandstone) and diameter of gravels in conglomerate appear to decrease northwards. Therefore, it may be concluded that the clastics in the Wano formation were carried in a basin from the southeast of the Kasari Peninsula.

4. Layer thickness in thin-bedded alternations

The thickness of each layer both sandstone and shale was measured in the middle part of 5) member (thin-bedded alternation) where continuous and undisturbed beds of some 80 are exposed at 400 m west of Wano. The cumulative thickness of each lithology in the set of alternating units is plotted on a graph of which the ordinate is the thickness of shale layer and the abscissa is that of sandstone layer (Text-figure 5; the method after KIMURA, 1966). As discussed later (p. 150), it is assumed here that a sandstone layer is turbidite in origin, and almost, if not all, of a shale layer are the sediments settled down during the resting

Fig. 3. Summary diagrams of directional sedimentary structures in the Wano formation at two localities.

Fig. 4. Orientation of sole features in the Wano formation.

Fig. 5. Cumulative graph of sandstone and shale layers.

period of turbidity currents.

Plots in the graph are approximately set on a curve and appear to show a positive correlation between the volume of turbidite represented by the volume (thickness) of sandstone and the duration of the resting period represented by that of shale. This fact, along with the poor content of clayey matrix and well-sorted nature of sandstone, may be attributed to that the material once accumulated at shallow place was displaced again into a basin to cause turbidity currents due to overload or seismic shock. The diversity may have been resulted from the inflow of a part or all of the accumulated sediments.

The average ratio in thickness between the sandstone and shale layers is $2/3$ in the graph. However, it does not hold in some beds but changes variably depending on the stratigraphic position. These changes must have happened not abruptly, but gradually as seen at the upper right of the graph.

5. Gravels of the conglomerate

The writer made observations on the gravels of conglomerate at the following five localities; 1) western coast of Setta, 2) south of Wano, 3) north of Okari-yama, 4) Suno, and 5) coast of Beru. In the field, the portion where cobbles are crowded was selected at each locality, and 100 gravels larger than 1 cm in diameter were lithologically identified and measured. The measurement was done on the apparent longest-diameter because the conglomerate is so indurated that gravels are inseparable from the matrix.

Text-figure 6 shows their compositional percentages at each locality based on 9 components; muddy limestone, shale, fine-grained sandstone, coarse-grained sandstone, conglomerate, chert, quartzite, igneous rocks, indetermined.

rocks, and the indetermined. It indicated that the lithologic compositions are nearly uniform throughout four localities except Beru, where the gravels consist primarily of sedimentary rocks, and that the percentages of quartzite and igneous rocks increase proportionally northwards.

The features of these rocks are as follows;

1) The gravels of muddy limestone are generally 1 to 3 cm in diameter, but 15 cm at the northern coast of Beru. It is grey and muddy, in which many circular or elliptical dots of calcite, a few-tenth millimetre in diameter and probably fossils of pelagic organisms, are observed under microscope. Some are undoubtedly identified as globigerinid foraminifers. These gravels may be supplied from the limy nodules in the underlying formations.

2) The shale is divided into at least four types; a) grey, laminated, silty shale bearing many grains of quartz and muscovite, b) grey, clayey shale including many radiolarians, c) grey, silty shale with many fragments of plants, and d) the rest.

3) Fine-grained sandstone described here ranges from very fine to medium in the grain size. It is commonly 3 to 4 cm in diameter and about 0.5 of roundness, both being less than the values of coarse-grained sandstone. Fine-grained sandstone consists of two types; a) white grey, fine- and angular-grained, in which clayey matrix and grains of quartz are dominant, and b) brownish grey, medium and subangular- to subrounded-grained sandstone cemented with sparry calcite. The calcite cement attains almost 30%. The gravels of a) type are overwhelmingly prominent.

4) Coarse-grained sandstone is either a) white grey, subangular-grained sandstone which contains

Fig. 6. Gravel compositions of the conglomerate member.

some fragments of igneous rocks and metaquartzite with muscovite, and small portion of clayey matrix, or b) white grey, coarse- and angular-grained sandstone with fine flakes of muscovite.

5) Conglomerate is found only in the southwestern region, and may have been produced by contemporaneous erosion.

6) The percentage of chert is low among the gravels more than 1 cm in diameter, but quite high in those less than 1 cm. Chert is greenish or bluish white, with or without radiolarians. Radiolarian chert appears less abundant than the ones without radiolarians.

7) Micaceous quartzite, and fine to medium-grained quartzite without accompanying mineral are seen. Orthoquartzite showing the secondary quartz-overgrowth could not be recognized in the collected gravels.

8) Muscovite granite, biotite-muscovite granite, dacite, and quartz-porphyry are distinguished in the igneous rocks. The granite is most predominant among them.

9) The gravels of which rock name could not be given owing to severe weathering are grouped under the name of the indetermined.

Besides the rocks described above, a few gravels of metamorphic rocks have been identified as gneiss, muscovite schist, biotite-muscovite schist, and garnet-biotite-quartz schist.

6. Mineral composition of sandstone

Mineralogical examination on light minerals was carried out on sandstones of 4) and 6) members (sandstone). Mode of the light minerals was determined based on counting of 1,000 grains in each thin section using the Swift point-counter.

All the samples are fine- to medium-grained sandstone which is commonly composed of about 65% of quartz and chert, about 25% of feldspars, 5% of rock fragments and matrix, a little muscovite and Fe-chlorite, and others. The grain of quartz is angular to subangular in roundness; a few ones show wavy extinction under microscope. The second component is potash feldspar, some of which were identified as microcline. Potash feldspar has been almost always altered. Plagioclase makes up about 3 to 4% and belongs to albite or oligoclase. The percentage of feldspars is around 30% in the middle sandstone member while it is less than 25% in the upper member. Muscovite and Fe-chlorite make only a few percentages in sandstone of the Wano formation, but they are good indices of the formation. A few percentages of rock-fragments consist of black shale in most, chert, and igneous (granitic and andesitic) rocks; all of which are 1 mm in diameter. Clayey matrix gets only 3 to 5%. Calcite veins are rarely seen.

The result of the modal studies was plotted in a tri-

Fig. 7. Compositional diagram of sandstones.

angular diagram with the following three end members; a) quartz and chert, b) feldspars (both potash feldspar and plagioclase), and c) rock fragments and matrix (Text-figure 7). In this diagram, the data examined on sandstones of the Akakina formation were also indicated for the purpose of comparison. It shows a compositional difference between two formations; then, the sandstone of the Wano formation falls in the type of arkosic arenite, while those of the Akakina formation an intermediate type between arkosic-arenite and -wacke, according to the classification by WILLIAMS, TURNER, and GILBERT (1954).

FOSSILS IN THE WANO FORMATION

The fossils other than ichnofossils were found in 2) member (conglomerate), 3) member (shale), and 5) member (thin-bedded alternation of sandstone and shale).

a) 2)member (conglomerate)

The following fossils, though all indetermined, were found within the matrix of the conglomerate in this member: two imperfect moulds of pelecypod at the road-cutting 500 m southwest of Wano; many pelecypods about 10 cm large with dominant growth-lines and without radial rib, in a carbonaceous pebble conglomerate at the coast south of the above locality; and some impressions of pelecypod and gastropod at 600 m west of Many. Besides these fossils, some globigerinid foraminifers occur in the cobbles of muddy limestone.

b) 3)member (shale)

The writer collected quite a few fossils of land plants, molluscs, and echinoids from the nodules in 3) member (shale) at Okari-yama. The land plants are fragments of leaf and cone, only some of which can be identified as

follows: *Sequoia*, *Angiopteris*, *Cyclobalanopsis*, and *Liquidambar* (identified by H. Matsuo). Molluscan remains were identified as *Acila* (*Truncacila*) sp., *Lucina* sp., *Nuculana* sp., and *Semifusus* sp. by A. Mizuno. According to A. Morishita, echinoids belong to a species of *Paraster*; the genus appears to be abundant in Eocene, though it ranges from Eocene to Recent. These fossils are so poorly preserved that none of them are identified beyond generic names.

c) 5) member (thin-bedded alternation)

Furthermore, some specimens of "large foraminifer" were collected from a sandstone layer in this member at Amami Airport in Setta. The specimens were identified as *Nummulites* sp. by S. Hanzawa, who assigned the age of the species to be Eocene.

ENVIRONMENTAL ANALYSIS OF THE WANO FORMATION

It can be said that some clastics of the Wano formation are turbidites, because of their lithological and sedimentary characters; lateral changing of the rock-facies, rhythmic thin-bedded alternations of rocks, poor occurrence of fossils, and existence of sole markings and graded beddings. The present writer made a special effort to observe the thin-bedded alternation members in terms of sedimentological features.

He presumes that the clastics in thin-bedded alternation members of the Wano formation were more or less moved and redeposited from their original site of deposition during sedimentation, as mentioned in "4. Layer thickness". The materials which has once deposited and accumulated at the place like the present continental shelf seem to have slipped down from there and flown into the deep basin to result in turbidity currents. Moreover, individual sandstone layer is thin and develops parallel lamination excellently, while well-defined and large groove- and flute-marks, as well as the graded bedding and cross lamination are poorly represented. Slumping structures are not seen. Accordingly, it is thought that the basin which deposited thin-bedded alternation members was far from the slope and the force of currents was weak.

Because the erosive force relative to the bottom sediments seems to have been weak as described above, it is argued that the unrecognized intervals in sandstone layers, which are supposed to be truncated out by several authors (e.g., BOUMA, 1962), were eroded out not after deposition of the whole sediments carried in by a turbidity current, but during their deposition. The intervals were taken away by the working of oscillated or separated currents in turbidity mass. A similar procedure may have caused the formation of various graded beddings other than simple and positive one.

Each bed of the thin-bedded alternation of sandstone

and shale can be divided into lower sandstone layer and upper shale layer. Each boundary between the layers shows a rather smooth plain, where many ichnofossils are concentrated. The fossils are mostly remains of post-depositional burrowers which penetrate the muddy layer and dwell along the sand-mud interface, whereas some are undoubtedly trails of creepers which postdated the time of turbidity flow and lived during the resting period. Such facts show that the interface between two lithologies indicated breaks both in the grain size and during a sedimentation period. A white tuff band with almost uniform thickness is interbedded within the lower part of the shale layer exposed at road-cutting, northwest of Wano. Thus, it seems to be more likely that the deposits brought by turbidity currents are only sandstone layers, and shale layers are sediments "native" to the site of deposition.

These thin-bedded alternation members change gradually to the sandstone members, and the rock-facies of sandstone layer resembles between both members. The sandstone member consists of alternations of thick sandstone layers and very thin shale layers, and also preserves sole markings. Accordingly, the present writer thinks that the sandstone members were also formed in the similar depositional process as the thin-bedded alternation members. Paying attention to very thin shale layer of the sandstone members, moreover, we can learn that each resting period between turbidity currents become shorter, and the volume of the sediments supplied increased abruptly, compared with those of the thin-bedded alternation of sandstone and shale members.

One of the peculiar rocks in the Wano formation is conglomerate, which also considered to be the sediments by turbidity currents; because,

- 1) the conglomerate member consists of many stratified beds with well-defined graded beddings,
- 2) both size of gravels and thickness of beds decrease generally northwards, and
- 3) a unit 20 m thick consisting of thin-bedded alternations of shale and granule conglomerate or fine-grained sandstone occurs conformably on the conglomerate member. The sedimentary basin where the conglomerate was deposited, however, seems to have been shallower and closer to the paleoslope causing turbidity currents than those of the other members, and it may belong to fluxo-turbidite (term after DZULYNSKI *et al.*, 1959), because the member has shells and cobbles, and the shale member setting on this member yields remains of molluscs, echinoids, and plants.

Besides above members, two shale members exist in the Wano formation; 3) member overlying the conglomerate member holds silty shale and fossiliferous nodules, whereas the top member consists of only dark

Fig. 8. Lateral change of the rock-facies in the Wano formation; 1) sandstone, 2) conglomerate, 3) shale, 4) sandstone, 5) thin-bedded alternation of sandstone and shale, 6) sandstone, 7) thin-bedded alternation of sandstone and shale, and 8) shale members.

grey shale. This difference between these members seems to reflect the difference in depth of sedimentary basin.

As shown in vertical sections of the Wano formation, 4) member (sandstone) and 5) member (thin-bedded alternation) are commonly thicker than 6) member (sandstone) and 7) member (thin-bedded alternation) respectively. The Wano formation shows a tendency to increase the fine-grained sediments upwards, and all boundaries between their members are gradational. On the basis of all these evidences, it is interpreted that the sedimentary basin of the Wano formation was somewhat shallow at the beginning, and became deeper gradually, although accompanying with occasional fructuations.

Text-figure 8 indicates a lateral change of the Wano formation obtained on the eastern limb of the huge syncline. It shows that each thickness of the sandstone members decreases and each one of the shale members increases towards left hand of the figure (*i. e.*, northwards). The thickness of the conglomerate member is not accordant with such a tendency of the sandstone members, though the gravel size of the conglomerate decreases generally northwards. As described in "3. Current direction", sole markings in both the sandstone and thin-bedded alternation members indicate that the clastics were supplied from the southeastern side. These facts may indicate that the source area of at least most of the Wano formation was situated in the east to south of Amami-oshima, where the vast Philippine Sea occupies at present.

From the evidence of the gravel composition of conglomerate in the Wano formation, it can be said that the sedimentary rocks such as sandstone, shale, chert, and muddy limestone, igneous rocks such as granite, dacite, and quartz-porphry, and metamorphic rocks such as schist and gneiss were cropped out in the source area of the formation at least some time during

the deposition of the Wano formation. However, the units which those rocks were derived from are unknown, because they seem to be submerged beneath the ocean at present.

3) member (shale) yields land plants of *Sequoia*, *Angiopteris*, *Cyclobalanopsis*, and *Liquidambar* at the top of Okari-yama, and it can be inferred that there was a temperature to subtropical climate during the deposition of the Wano formation.

CORRELATION

It became certain that the Wano formation was deposited during Eocene, as evidenced from *Nummulites* sp. found in the middle portion of the formation. Although only ichnofossils were seen in the Akakina formation, it can be concluded that the formation predates the Wano formation, hence pre-Eocene, on the basis of the following informations from the Akakina formation;

- 1) both sandstone and shale are lithologically different from those of the Wano formation,
- 2) the regionally metamorphosed slate and phyllite can be seen,
- 3) the complex folds and sheared structures are observed, and
- 4) the formation is intruded by Late Eocene granite.

Besides these formations, the pre-Neogene formations such as Naon, Odana, Shinmura, Naze, and Ogachi are developed in the island (HATAE *et al.*, 1959). KONISHI (1963, 1965) and KONISHI *et al.* (1966) have described the zonal distribution and correlations of the formations in the Ryukyu Islands. The report by MATSUMOTO *et al.* (1966) has tried to correlate the basement rocks in Amami-oshima with those in Kyushu as follows:

Amami-oshima South Kyushu		Geological age
Odana formation	Isshochi group	Upper Cretaceous(?)
Shinmura formation	Kawabe group	Lower Cret.-Jurassic (?)
Naze formation	Youra group	Lower Cret.-Jurassic (?)
Ogachi formation	Hyuga group (lower)	Upper Cretaceous
Wano formation	Hyuga group (upper)	Lower Tertiary

HASHIMOTO (1962) investigated thoroughly the rocks of the Shimanto terrain in Kyushu, and classified them into six belts; from northwest to southeast, the Saeki, Kamae, Nobeoka, Takakumayama, Nichinan, and Kumage.

Here, the present writer discusses an alternative scheme of correlation between the basement rocks in Amami-oshima and those of Shimanto terrain in Kyushu (Table 1).

The Isshochi and Kawabe groups (Saeki belt), and

Table 1. Correlation of the rocks of the Shimanto belt in Amami-oshima and those in Kyushu.

Belt	AMAMI-O-SHIMA					SOUTH KYUSHU				
	KUNIGAMI		SHIMAJIRI		KUMAGE	KUNIGAMI		SHIMAJIRI		KUMAGE
	SAEKI	KAMAE	NOBEOKA-TAKAKUMA-YAMA	NICHINAN	KUMAGE	SAEKI	KAMAE	NOBEOKA-TAKAKUMA-YAMA	NICHINAN	KUMAGE
AGE										
CENOZOIC	M									
	O									
	E									
	P									
MESOZOIC	K	ODANA F.		WANO F.					NICHINAN G.	ISSO F.
		SHINMURA F.		OGACHI F.		ISSHOCHI G.		HYUGA G. (upper)	unnamed g.	
			NAZE F.	AKAKINA F.		KAWABE G.		HYUGA G. (lower)		
	J						KAMAE G.	unnamed g. near Takakumayama		MIYANO KUNUR F. / MAHUR F. / GE G.
	T						KITAGAWA G.			MUGIO F.

Kamae and Kitagawa groups (Kamae belt) are successively conformable each other. The Kawabe group resembles lithologically the Kamae group, most of which, however, could be older than the Kawabe group, because the latter is more highly metamorphosed than the former (regional metamorphism), though both may be correlative in part (HASHIMOTO, 1962). The Odana and Shinmura formations in Amami-oshima may be compared to the Isshochi and Kawabe groups respectively, in terms of their distributions and rock-facies, as already proposed by MATSUMOTO *et al.* (1966). According to HATAE *et al.* (1959), the Naze formation consists of slate which is rarely phyllitic, sandstone, and "schalstein". This formation seems to be correlated to the Kamae group and a part of the Kitagawa group, though more detailed studies are required before reaching any conclusions.

Recently, an ammonite was found in a block of shale, derived from the Ogachi formation (ISHIKAWA and YAMAKUCHI, 1965). The specimen suggests the Cenomanian or Turonian age, hence the Ogachi formation is dated as the Upper Cretaceous (MATSUMOTO *et al.*, 1966). The pre-Eocene Akakina formation comprising meta-basalt with pillow structures, reddish purple shale, phyllite and others, bears resemblance to the Naze formation rather than the Ogachi formation which is exclusively composed of shale, sandstone, and their thin-bedded alternation. Namely, the Akakina formation may correspond to the rocks* of the Takakumayama belt, which appears to be lithologically similar to the Kamae group.

According to HASHIMOTO (1962), both the lower and

* Takakumayama and Gonohara formations described by KAWACHI (1962).

upper subgroups of the Hyuga group in the Nobeoka belt are Paleogene. The present writer thinks, however, that the lower and upper subgroups of the group may possibly be correlated to the Ogachi and Wano formations respectively, on the basis of stratigraphical and lithological evidences, and supports the conclusion of MATSUMOTO *et al.* (1966). Along the southeast side of the Takakumayama belt, the Nichinan belt characterized by the wide distribution of Nichinan group develops, which ranges from Lower Oligocene to Lower Miocene (SHUTO, 1963). On the other hand, the sequence from the Upper Eocene to Lower Oligocene is found in the southernmost part of the Osumi Peninsula, which is dated by foraminiferal fauna (KUWANO, 1960). HASHIMOTO (1962) noted that the Nichinan group is partly correlated to the upper subgroup of the Hyuga group.

The units belonging to the Kumage belt are Mugio, Hunayuki and Miyanoura formations, and Kumage group. Most of the Kumage group at Tanega-shima can be compared with the Hunayuki and Miyanoura formations at Yaku-shima, and all the three were said to be Paleogene in age (HASHIMOTO, 1962). However, the present writer would interpret that the Hunayuki formation and the Kumage group might be partially correlated to the rocks of the Kamae and Takakumayama belts (thus probably pre-Eocene). Although the rocks of the Kumage belt are not exposed in Amami-oshima, many pebbles of phyllite, meta-basalt, and others are found in the beach gravels at the east coast of Kikai-jima (30 km east of the Kasari Peninsula), where the pre-Neogene basement complex is not exposed. Therefore, the rocks of the Kumage belt may be submerged beneath the water east of Amami-oshima.

Though it is not shown in Table 1, the Ogachi formation and the Wano formation may be correlated to the Kayo formation in Okinawa-jima, judging from their rock-facies and fossils (KONISHI *et al.*, 1966).

Because correlatives of both the Nobeoka and Takakumayama belts can not be separated in Amami-oshima as originally defined by HASHIMOTO (*ibid.*) in South Kyushu, the present writer recognizes the following five belts in the basement rocks of the Shimanto terrain; Saeki, Kamae, Nobeoka-Takakumayama, Nichinan, and Kumage belts. If these belts be referred to the belts defined by KONISHI (1965), they may be compared as follows;

Saeki and Kamae beltsKunigami belt
Nobeoka-Takakumayama
and Nichinan belts Shimajiri belt
Kumage beltKumage belt

CONCLUSIONS

1. The following formations are exposed in the Kasari Peninsula of Amami-oshima; Late Mesozoic Akakina, Eocene Wano, and Quaternary sediments varying from limestone, coastal terrace sediments, fluvial deposits, to beach deposits. Besides, granite intruded into the Akakina formation. The Akakina formation is composed of phyllite, slate, shale, sandstone, thin-bedded alternation of sandstone and shale, and greenstone, whereas the Wano formation consists of sandstone, shale, their thin-bedded alternation, and conglomerate.

2. The Wano formation attaining about 800 m in thickness is lithologically divided into 8 members. Judging from the rock-facies and sedimentary structures in the formation, conglomerate in the lower members is fluxo-turbidite, and sandstone layers in the other members of the formation are turbidites. Internal structures observed within the sandstone layers are graded bedding, parallel lamination, and cross lamination, in which the second is most prominent. Most of sole markings found at the bottom of sandstone layers are small and shallow flute- and groove-moulds, besides undetermined and indistinct scour marks.

3. From the rock-facies and sedimentary characters of the Wano formation, it is concluded that the sedimentary basin of the formation was rather shallow and close to the slope causing turbidity currents initially, and gradually became deeper and further distant from there later.

4. The current direction obtained from sole markings and cross lamination in the turbidites of the Wano formation shows that the clastics of the formation were carried into the basin from south-east of Amami-oshima, where it is submerged beneath the Philippine Sea at present.

5. In the provenance of the Wano formation, sandstone, shale, muddy limestone, chert, granite, dacite, quartz-porphry, quartzite, schist, and gneiss were cropped out, as shown by gravel analysis of conglomerates.

6. A few specimens of Eocene-type *Nummulites* were found from the thin-bedded alternation of sandstone and shale of the Wano formation. Land plants yielded in the lower part of the formation show that there was a temperate to subtropical climate during the deposition of the formation.

7. The Wano formation is now dated as Eocene. Although the Akakina formation appears to be unfossiliferous except a few ichnofossils, it is presumed to be Late Mesozoic, because the formation is older than the Wano formation as structurally defined, and lithologically similar to the rocks cropping out near Takakumayama in South Kyushu dated as Late Mesozoic by HASHIMOTO (1962) rather than the Late Cretaceous Ogachi formation to the west of the Kasari Peninsula. The Wano and Akakina formations are correlated respectively to the upper subgroup of the Hyuga group and the rocks cropping out near Takakumayama which belong to the southern belt of the Shimanto terrain in South Kyushu.

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奄美大島の和野層（始新統）

石 田 財 司

（要 旨）

奄美大島の笠利半島には、泥質岩を主とする赤木名層、砂岩・砂岩頁岩細互層を主とする和野層、花崗岩、および、これらを不整合に被う第四紀の礫層などが分布する。赤木名層と和野層は北北東方向の走向で、西に急傾斜する。さらに、和野層は向斜構造を形成し、赤木名層と断層で接している。

本論文では、おもに、和野層の堆積学的検討をおこなった。和野層は、砂岩・砂岩頁岩細互層・頁岩・礫岩から成り、全層厚約800mである。本層は、岩相上8部層に分けられ、上部へと細粒堆積物が優勢になっている。岩相の水平変化、規則的な互層、sole markings、内部堆積構造などから、和野層中の砂岩単層は turbidites であり、礫岩層は fluxo-turbidites であろう。また、current marks の観察により、これらの堆積物は本地域の南東部より運び込まれたと考えられる。この供給地域には、砂岩・頁岩のほか、泥質石灰岩・チャート・花崗岩・石英安山岩・片岩・片麻岩などが露出していたであろう。一方、岩相変化や堆積構造の種種の特徴は、和野層の堆積盆地が、初期には turbidity currents を生ぜしめた paleoslope に比較的近かったが、後期へと次第に遠くなり、深くなったということを示す。

和野層より発見した化石には、ウニ・二枚貝などの動物化石、亜熱帯性気候を示す植物化石のほか、始新世型 *Nummulites* があり、和野層は始新統であることが明らかとなった。赤木名層から化石は得られなかったが、地

層の固結度・変形度が和野層より高く、始新世と年代測定されている花崗岩に貫入されていることを考えれば、本層は先始新統であることは疑いない。

以上の結果、赤木名層と和野層は、それぞれ、九州に露出する四万十累帯の高隈山付近の地層（白亜系？）と日向層群上部亜層群に対比できよう。

Alphabetical list of place names

Akakina	赤木名	Naon	名音
Amami-oshima	奄美大島	Naze	名瀬
Beru	辺留	Odana	大棚
Gamo-zaki	蒲生崎	Ogachi	大勝
Ishigaki	石垣	Okari-yama	大刈山
Kaminoko	神子	Setta	節田
Kasari	笠利	Shimajiri	島尻
Kawauchi	川内	Shinmura	新村
Kayo	嘉陽	Suno	須野
Kikai-jima	喜界島	Taira	平
Koshiki-jima	甌島	Tomori	土盛
Kujirahama	鯨浜	Tsuchihama	土浜
Kumage	熊毛	Ushuku	宇宿
Kunigami	国頭	Uttabaru	内田原
Manya	万屋	Wano	和野
Motobu	本部	Yo	用
Myogan-zaki	明神崎	Yode-yama	淀山

Explanation of plate

- Fig. 1. Thin-bedded alternation of sandstone and shale of the Wano formation. White layers are sandstone. Left hand in photograph is lower side of this unit.
- Fig. 2. Cobble conglomerate of the wano formation at southwestern coast of Setta. Lower surface of the bed is left hand in photograph.
- Fig. 3. Indistinct sole markings on the lower bedding plane of sandstone layer. Piece form thin-bedded alternation member of the Wano formation.
- Fig. 4. Cross section of sandstone layer in thin-bedded alternation member of the Wano formation, which is cut in parallel with the axis of sole markings. Such a sedimentation type in which parallel lamination develops is frequently found in the Wano formation. ($\times 0.6$)
- Fig. 5. *Paraster* sp. collected from the shale member of the Wano formation at Okariyama. ($\times 1.2$)
- Fig. 6. Specimen of *Nummulites* sp. from the Wano formation. ($\times 8$)