TECTONICS OF THE RYUKYU ISLAND ARC

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The geological and structural contrast between the north and central Ryukyus and the south Ryukyus has been significant since the Late Mesozoic. The difference seems to correspond to that of the nature of the Philippine Sea floor facing the Ryukyus, i.e. the Daito Ridges and Amami plateau to the north and deeper basin to the south. The north and central Ryukyus were a separate tectonic unit from the south Ryukyus from the Late Mesozoic to Middle Tertiary. Subsequently they have united to form an island arc as the island groups shifted southeastwards with different rates in the Late Tertiary to Quaternary.

1. Introduction

The Ryukyu islands are a typical island arc, 1,200 km long, lying between Kyushu and Taiwan at the northwestern Pacific margin. They are composed of the Ryukyu Trench on the Pacific side, a row of islands, a volcanic belt and the Okinawa Trough on the continental margin. The islands are divided morphologically as well as geologically into three groups: the north Ryukyu Osumi islands, the central Ryukyu Amami and Okinawa islands, and the south Ryukyu Miyako and Yaeyama islands. They are separated by the Tokara Channel and the Miyako Depression, which represent strike-slip fault zones.

The structural framework of the islands was studied by KONISHI (1965). His structural zonation paralleled the zonation of the pre-Miocene basement complex of Southwest Honshu: the Ryukyu islands were interpreted as the southwestern continuation of Outer Zone of Southwest Japan modified into an echelon configuration by the left-lateral transcurrent dislocations of the Tokara Channel and the Miyako Depression. NAKAGAWA (1974) correlated the island arc system of the Ryukyu islands with that of Northeast Japan. In this paper, the author attempts to discuss the island arc system from a different point of view. Recent investigations verified that the geological and structural discontinuity of the north-central Ryukyus and south Ryukyu is significant. The geological and structural histories of both island groups are quite different throughout the period of Mesozoic to Miocene. Thereafter, the island groups united into a single island arc.

2. Basement of the Islands

The basement rocks of central Ryukyu are composed of Late Paleozoic eugeosynclinal sediments, including slate, chert, limestone and diabasic green rocks, whereas the Yaeyama metamorphic rocks—phyllite, black schists and green schists including the glaucophane schist facies rocks—are seen only in south Ryukyu.

The Late Paleozoic eugeosynclinal sediments are correlated to the Upper Paleozoic groups of Kyushu and Shikoku to the north and also to those of Taiwan to the south. The structural trend of the basement group is not necessarily parallel to the general trend of the

Fig. 1. Structural trend of the Paleozoic group in the Ryukyu Islands.

island arc but is more or less diverse (Fig. 1). The variation of the fold axes of the Paleozoic group seems to have resulted from the later dislocations than the deformations of the Mesozoic orogeny.

The Yaeyama metamorphic rocks are constructed mainly of two fold systems with different orientations. The principal fold, which trends in NW-SE direction, has a wavelength of several kilometers and is clearly oblique to the trend of the island arc. The preferred orientation of minerals is parallel to the fold axis. A minor fold with EW axes is superimposed on the principal fold. Shear zones and faults are well developed parallel to the minor fold. Blocks of the metamorphic rocks crop out locally through the Lower Miocene sandstone formation along the EW faults. It seems therefore that the EW faulting was activated parallel to the island arc in the Middle to Late Miocene.

Paleomagnetic study of the Eocene volcanic rocks reveals a clockwise rotation of 40° of the Yaeyama islands (south Ryukyu) resulting in the present NW-SE trend of the metamorphic rocks (SASAJIMA, 1977). The original trend, therefore, should be in east-west direction parallel to the present direction of the island arc.

Radiometric ages of the Yaeyama metamorphic rocks are 174 my (K-Ar method), 195 my (Rb-Sr method) (SHIBATA *et al.*, 1968, 1972). The Sambagawa metamorphic rocks representing facies similar to the Yaeyama metamorphics, have ages of 82–102 my, which are much younger than the Yaeyama rocks. But the Sangun metamorphic rocks indicate similar ages of 159–175 my. Both Sambagawa and Sangun rocks are from Honshu, Shikoku and Kyushu. The green schist of the Tananao belt of Taiwan is re-

ported to have much younger ages of 82–14 my (YEN, 1975). The Yaeyama metamorphic rocks then seem to be correlated to the Sangun rocks so far as the radiometric ages are concerned. The original sedimentary rocks are considered to be of the Late Paleozoic age but no fossils have yet been found from the metamorphic rocks.

3. *The Shimanto Belt*

The terrane of the Shimanto supergroup of Late Mesozoic to Early Tertiary age continues southwards to the north-central Ryukyus from Kyushu, Shikoku and Honshu where the supergroup signifies the geosynclinal sediments in the outer belt of Southwest Japan on the Pacific side. The upper horizon of the supergroup in central Ryukyu is composed of thick and coarse sandstones containing Eocene nummulites. The distribution of the supergroup is limited to the north-central Ryukyus, whereas calcareous littoral sediments intercalated with andesite and pyroclastic rocks of Eocene age are seen in south Ryukyu (SHIRAO *et al.*, 1976). The Shimanto supergroup of the north-central Ryukyus is severely deformed to form isoclinal folds and SE-verging thrust faults. It is also slightly metamorphosed to black and green phyllites and partly to green schists.

The Eocene formation of south Ryukyu shows different sedimentation facies from that of the northern islands and no deformation and metamorphism except mere tilting and later faulting. The area of south Ryukyu has therefore been a part of stable land mass since the Eocene sedimentation. KONISHI (1965) stated that the Eocene basin of south Ryukyu formed an inner stable zone against the Shimanto belt, which formed the outer mobile zone of the islands arc. Accordingly, the islands of south Ryukyu have had to shift more rapidly southwards so as to form the present Ryukyu island arc.

4. *Miocene and Eocene Volcanism*

The inner zone of the north-central Ryukyus represents a line of recent volcanic islands, some of which are still active forming a present volcanic front. The basement of the volcanoes is constructed usually of volcanic and pyroclastic rocks of Miocene to Pliocene age which are altered to show greenish color by hydrothermal solution. Thus, they are collectively called "Green Tuff Volcanics" of Neogene age similar to those in the main Japanese islands. Marine geological investigations demonstrated that the volcanic and pyroclastic rocks are distributed in a 100 km wide zone in the inner zone and the Okinawa Trough of the north-central Ryukyus, but not of south Ryukyu (HONZA, 1977).

Pyroclastic rocks and andesite flows are found conformably within the Eocene littoral sediments in south Ryukyu (SHIRAO *et al.*, 1976). Their occurrence seems to be similar to that of the "Green tuff" rocks, but the age is quite different. Moreover, the pyroxene andesites of south Ryukyu show a lower alkali-lime index (58.3) than those from the Miocene andesites (61.8) of the north-central Ryukyus (MATSUMOTO, 1964). The Eocene volcanism cannot be traced to Taiwan but might be correlated with that of the Philippines. Here again, the contrast of volcanism in age and character is remarkable between the north-central Ryukyus and south Ryukyu (Fig. 2).

5. *Distribution of the Yaeyama Group*

The Yaeyama group, distributed in the Yaeyama islands of south Ryukyu, the northern part of Taiwan and the Senkaku islands, is composed mainly of sandstone with

Fig. 2. "Green Tuff Volcanism" in Miocene and Eocene.

intercalations of mudstone and is characterized by coal beds, cross laminae and trace fossils signifying littoral sediments.

Palynological investigation reveals the age of the sediments to be the Lower Miocene (TAKAHASHI and MATSUMOTO, 1964). The group is correlated with the Lower Miocene series of Taiwan and northern Kyushu by the heavy mineral assemblage also (OBARA and MATSUMOTO, 1964). The mineral composition is of zircon, tourmaline, garnet, and often associated with rutile, staurolite and monazite. These minerals are probably supplied from granite and gneiss, which are never found in the neighbouring islands nor Taiwan, but are abundant in the southeast coastal area of China. Therefore, the geological development of south Ryukyu should be interpreted in connection with the geology of the southeast China.

The Yaeyama group is slightly tilted structurally and faulted. This again shows that the Yaeyama islands and their environs have been in stable conditions since Early Miocene.

6. The Shimajiri Basin

It is not until the Latest Miocene during the deposition of the Shimajiri group, that the north-central Ryukyus and south Ryukyu formed a common basin throughout the Ryukyu islands.

The sediments of the group, which are composed mainly of siltstone interbedded sand-

Table 1. Marine geological and structural contrast of the north-central Ryukyus to south Ryukyu around the Ryukyu islands after HONZA (1977).

	North-central Ryukyus	South Ryukyu
Okinawa Trough	Tokara volcanic belt	None
	Neogene volcanism	None
	1,000 m at the deepest area	2,200 m at the deepest area
	Amami Trough at the eastern margin	None
	Minor fault group at the western edge	None
	Thick turbidite	Thin and less
Fore-arc slope	Neogene Shimajiri group	Quaternary and Neogene Shimajiri group
	Small frontal slope swell	Big swell zone at the frontal slope edge
Ryukyu Trench	Rough morphology of inner trench slope	Smooth inner trench slope
	V valley and disturbed morphology at the bottom of the Trench	Flat bottom and turbidite

stone and tuff in the upper part, range from the Upper Miocene to the Lower Pleistocene according to the investigation of foraminiferas (LEROY, 1964; NATORI *et al.*, 1972; UJIE and OKI, 1974).

The lower portion of the group shows a deep water paleoenvironment, indicating relative rise of sea level during the Uppermost Miocene to Pliocene. Then rapid regression occurred during deposition of the upper horizon of the group on the basis of benthonic foraminiferas as well as molluscan fossils (LEROY, 1964; NODA, 1976).

Southeastward shift of the basin occurred during the Shimajiri stage accompanied by basement arching. The Ryukyu island arc formed in association with the uplift of the Shimajiri group along the arc, simultaneous with the formation of the Okinawa Trough and probably the Ryukyu Trench. This was at the end of the Lower Pleistocene.

7. Marine Geological Results

Marine geological research has been carried out around the Ryukyu islands by the Hakurei Maru of the Geological Survey of Japan (HONZA, 1977). Honza stressed that significant differences in the marine geology are observed between the southern part of Ryukyu (south Ryukyu) and the northern part of Ryukyu (north-central Ryukyus). The contrast of the geology and structure of the sea floor between the south and north-central Ryukyus around the Ryukyu islands is shown in Table 1. It is particularly apparent in the difference of the nature of the Philippine Sea floor facing the north-central and south Ryukyu.

8. Tectonic Unification of the Islands

From the above considerations, it may be concluded that the geology and tectonics of south Ryukyu differ from those of the north-central Ryukyus. The metamorphism of the Yaeyama metamorphic rocks had completed by the end of the Jurassic time and the

Fig. 3. Distribution of the Shimanto supergroup which shows an oroclinal bent at the southwestern coast of Kyushu resulted from the Kyushu western marginal shear (K.W.M.S.).

region thereafter has been in stable conditions, whereas in the north-central Ryukyus eugeosynclinal stage has continued until the end of the Paleogene and the Early Miocene age partly.

The ENE-WSW trend of the Shimanto supergroup changes almost sixty degrees to the south at the western coast of Kyushu which is called "Hokusatsu Bend" (Fig. 3). This oroclinal bend was produced by the Kyushu western marginal shear (KIZAKI, 1978) with the left-lateral shift in the Middle Miocene age after the completion of the main folding stage associated with thrust faulting. The clockwise rotation of south Ryukyu, mentioned earlier, occurred in the Oligocene time.

In Taiwan, the formations including the Lower Miocene sediments are bent to the east at the northeastern edge of the island where a right-lateral shearing of probable Middle Miocene age has been reported (YEN, 1975).

It is therefore probable that the southeastward shift of the Ryukyu proto-islands culminated in the Middle Miocene and continued thereafter, protruding relatively to the southeast between Kyushu and Taiwan. At that time the Tokara Channel and Miyako Depression were also activated as left-lateral faults. From these facts, it may be inferred that the Ryukyu islands have been shifted differentially southeastwards particularly since the Middle Miocene associated with strike-slip faults to form the modern island arc in the Plio-Pleistocene time. Prior to the Middle Miocene, the north-central Ryukyus and south Ryukyu had experienced different geological and structural histories.

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