Back-arc rifting in the Okinawa Trough

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Geological and geophysical data reveal that the Okinawa Trough shows incipient continental rifting, and crustal separation started from about 2 Ma. The early extensional movements in the trough are probably of Miocene age. In addition to the Miocene phase, two main periods of extension are recognized: a Pleistocene phase between 1.9 and 0.5 Ma and the present day phase. During the stage short central rifts (Central Grabens) were formed. The opening however, may have occurred only in the southern part of the trough basin having an average half spreading rate of 2 cm yr\(^{-1}\) since Early Pleistocene time, producing its present width of several tens of kilometres. These activities were well represented by igneous intrusions, sedimentary facies and sedimentary structures in and around the Okinawa Trough. The width of the zone affected by back-arc extension (defined as Greater Okinawa Trough) is larger than the present Okinawa Trough, whose width is 200–250 km. The present form of the Greater Okinawa Trough started to form at the same time as that of the Okinawa Trough.

Keywords: Okinawa Trough; Back-arc rifting

Introduction

The Okinawa Trough is a back-arc basin of the Ryukyu Arc (Figure 1). Konishi and Sudo (1973) suggested that the Okinawa Trough has been spreading since Middle Miocene time based upon geologic evidence from the Ryukyu Islands. However, based upon analyses of single channel airgun reflection profiles, Herman et al. (1978) proposed that there is an unconformity between the upper and lower sediments (their Unit A and B) in the southern Okinawa Trough, and that back-arc spreading was initiated sometime after Late Miocene–Early Pliocene time when the Ryukyu Arc was rifted from the continental margin. They suggested that the basin of the Okinawa Trough had opened to almost its present day width before the deposition of the thin upper sediments of Unit A began and that Unit B was probably deposited in the basin before the major period of spreading ceased. Units A and B, however, were not dated. Subsequently, a two ship refraction study was carried out in the southern Okinawa Trough (Lee et al., 1980). The Upper mantle was found to be very shallow in the Okinawa Trough, compared to the surrounding areas of the continental crust. Relatively young basalt was also found beneath the axial area of the trough. Lee et al. (1980) concluded that crustal separation has occurred in the southern Okinawa Trough from Pliocene to Recent time. None of these studies has discussed the northern and middle parts of the Okinawa Trough.

This paper presents a compilation of seismic reflection and refraction, dredging, magnetic anomaly and well data covering the entire Okinawa Trough area, all of which appear to support the existence of crustal separation in the Okinawa Trough since Early Pleistocene time.

Data

Submarine topography in and around the Okinawa Trough was contoured (Figure 1) using the Ocean Water Depth compilations of the Japanese Hydrographic Department, Marine Safety Agency of Japan and was supplemented by the author's own data. Most of the seismic reflection profiles used here are single channel data of the Geological Survey of Japan compiled by Kimura et al. (1979 and 1980), Kimura (1983) and Honza (1976). Data from the Ocean Research Institute, University of Tokyo (Kagami, 1975), US Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), US Naval Oceanographic Office (USNOO), R/V Hunt data (Wageman et al., 1970), Lamont-Doherty Geological observatory of Columbia University and the Hydrographic Department, Maritime Safety Agency of Japan were also reanalysed and compiled. Multi-channel seismic reflection profiles by the Japan National Oil Corporation (JNOC) were also used (Figure 2). Magnetic data from the Geological Survey of Japan, Kobe University and University of the Ryukyus were used (Figure 3). Seismic refraction data were mainly taken from Murauchi et al. (1968), Hayes et al. (1978), Leyden et al. (1978) and Lee et al. (1980). Dredge samples from the Ocean Research Institute, University of Tokyo and from the Geological Survey of Japan were also studied and offshore drilling data for oil prospecting carried out by JNOC and petroleum companies are reviewed in part (Figure 4).

Submarine topography

The topography of the Okinawa Trough (Figure 1) and surrounding vicinities is arranged in belts, from east to
Back-arc rifting in the Okinawa Trough: M. Kimura

Figure 1 Submarine topography in and around the Okinawa Trough based upon the map by Kimura (1983b). The contour interval is 200 m to 2000 m water depth; 1000 m for deeper areas. Ko, Koshiki Knoll; To, Tokara hill; Ga, Gama-sone; Yo, Yokogan-sone Bank; Am, Amami-o-shima; Ok, Okinawa-jima; Ry, Ryukyu-sone Bank; My, Miyako-jima; Is, Ishigaki-jima; Ir, Inomote-jima; Yk, Yonaguni Knoll; Td, Tokara depression; Md, Miyako depression (Kerama gap)
Figure 2 Track lines of seismic reflection profiles used in this study. (1) Area of dense survey lines carried out of the Geological Survey of Japan and the Hydrographic Department, Maritime Safety Agency of Japan; (2) seismic reflection survey lines by Geological Survey of Japan and JNOC; (3) Ocean Research Institute, University of Tokyo; (4) USNOO; and (5) Lamont-Doherty Geological Observatory of Columbia University. Thick lines show locations of seismic reflection profiles presented in the present paper, Figures 5, 6, 7, 8, 11, 12 and 14.
Figure 3 Map displaying magnetic anomaly profiles across the Okinawa Trough based upon data by the Geological Survey of Japan, Kobe University and University of the Ryukyus. Letters are magnetic profiles presented in Figures 16 and 17.
Structural framework

The structural map (Figure 9) shows the distribution of the main faults and tectonic provinces, all are believed to be related to the Okinawa Trough formation as deduced from seismic reflection, dredging and drilling data. The width of the zone affected by back-arc extension (defined as the Greater Okinawa Trough) is greater than the present Okinawa Trough (150 km) whose width is 200–250 km (Figure 9).

The topography of the Tunghai Slope and Tokara Ridge is rough and both features are regarded as marginal, tensile rifted zones of the Okinawa Trough. The Ryukyu Ridge Fault and Tunghai Shelf Fault have been active during the deposition of Early Pleistocene sediments (Layer C, Table 1). The Okinawa Trough is regarded as the area filled with deposits from Layer C upwards, two to three kilometres in thickness. The Greater Okinawa Trough and the Okinawa Trough have developed generally parallel to the Ryukyu Ridge. Central Grabens or rifts exist in the axial part of the Okinawa Trough in an en echelon pattern. The existence of the Central Graben of the Okinawa Trough was first noted by Kimura et al. (1975) in the middle area. Central Grabens in the southern part of the Okinawa Trough were found by Herman et al. (1978). In places the Central Grabens of the northern Okinawa Trough are half graben features. In many cases, intrusive bodies exist beneath the Central Grabens to make basal highs. In other words, the Central Graben is defined as the most recent fissure originating in response to uprisings of magma. Seismicity shows that the Central Graben is active and focal mechanism solutions show that the tensional axis is oriented in a north-south direction (Eguchi, 1982; Eguchi and Uyeda, 1983; Yamamoto and Tokunaga, 1981).

Stratigraphy

The stratigraphy in and around the Okinawa Trough (Table 1) is arranged as follows. Layer E: Acoustic basement consisting of pre-Miocene formations and igneous bodies of various ages. Layer D: Early to Middle Miocene sediments. The layer displays a stratified pattern in the multi-channel seismic reflection profiles but is opaque in the single channel seismic reflection profiles. In the area of the so-called 'Green Tuff' activities, characterized by Neogene volcanism in Japan (Matsumoto, 1979) and containing huge volumes of volcanic material, Layer D displays a massive acoustic basement pattern in both single and multi-channel profiles. It is correlated with the Yaeyama Group and Sasebo Group which contain thick sandstone and coal beds. Layer C: Stratified transparent layer. It shows a well stratified pattern in multi-channel records. Layer B is correlated with Late Miocene to Early Pleistocene sediments, called the Shimajiri Group in the Ryukyu Islands. The Shimajiri Group is mainly composed of shallow facies mudstone rich in foraminifera. Layer B: Well stratified transparent layer correlated with sediments from 2 Ma to Late Pleistocene time. Layer A: Transparent layer correlated with Holocene sediments.

In the Okinawa Trough, pre-Tertiary rocks of Layer E, which belong to the Inner Zone of Southwest Japan (Tanaka, 1977) have been dredged and drilled (St. K, 385, 199 and E in Figure 4). Late Cretaceous granitic...
Figure 5. Seismic reflection, gravity and magnetic anomaly profiles (L3) crossing the northern part of the Okinawa Trough. Location is shown in Figure 2. Tectonomorphic division (II, III, IV) and faults (TS-F, TO-F) are given in Figure 10. The arrow shows the Central Graben. Magnetic anomalies (γ) and gravity anomalies (mgal) (Joshima, 1978 and Joshima et al., 1978). ‘Sec’ represents two way travel time.

Layer $B$ can be divided into sub-layers $B_1$ and $B_2$, in ascending order by differences in dip and mode of deformation of the layers in the trough. Layer $B_1$ (Table 1) is regarded as ponded sediments in the Okinawa Trough that were derived from eroded materials during the formation of the marked unconformity between Layer $C$ and $B$ in the surrounding regions of the Okinawa Trough. It is clear that the Layer $B$ sediments in the trough are younger than the main Shimajiri Group based on relative stratigraphic position as seen in the profiling records. The Shimajiri Group should include the Olduvai Event because the uppermost Shimajiri Group in Miyako-jima island includes zone N.22 in age (Planktonic foraminiferal zonation of Blow, 1969) (Natori, 1976; Ujiie and Oki, 1974). Correlation of Pleistocene chronology from the exposures on the land areas around Okinawa Trough.
Figure 6 Seismic reflection, gravity and magnetic anomaly profiles (L26) in the middle Okinawa Trough. Location is shown in Figure 2. (γ) magnetic and (mgal) gravity anomalies (Miyazaki et al., 1976 and Murakami, 1976). Tectonomorphologic division (I to V) and faults (T-F, TS-F, TO-F, R-F) are given in Figure 10. The arrow shows the Central Graben (rift in this case). St. 398 shows the dredging station, with the dredged direction. Broken lines represent the boundary between Quaternary sediments and its basement or igneous rocks.
Figure 7. Seismic reflection, gravity and magnetic anomaly profiles (L6) in the southern Okinawa Trough. Location is shown in Figure 2. (γ) magnetic and (mgal) gravity anomalies (Ishihara and Murakami, 1976). The arrow shows the Central Graben. Tectonomorphologic division (I to V) and faults (T-F, TS-F, TO-F, R-F) are given in Figure 10.
suggests that the main part of Layer B1 sediments exist beneath the basins in the Okinawa Trough. B2 is offset by the Central Graben (Figure 14).

Undeformed sediments of Layer A, Holocene deposits, overly Layer B conformably in the trough basins. This unit unconformably overlies older units in the areas surrounding the islands in the Ryukyu Ridge.

In the middle part of the Okinawa Trough, igneous intrusions and some apparent volcanic extrusions exist which seem to be very young (Figure 6). Pleistocene igneous rocks were obtained from St. 398 (Figure 4). Young intrusions are also observed beneath the central axis of the northern and southern Okinawa Troughs.

**Unconformities**

Five major post-Mesozoic unconformities are recognized in and around the Okinawa Trough (Table 1). (1) Unconformity between Layer D and E, formed in Oligocene time; (2) C/D unconformity in Middle to Late Miocene time; (3) B/C unconformity in Early to Middle Pleistocene time; (4) unconformity in Layer B2; (5) A/B unconformity in Late Pleistocene time. The

**Table 1** Stratigraphic correlation table in and around the Okinawa Trough. Neogene chronostratigraphic scale is after Harland et al. (1982) but age of the Plio-Pleistocene boundary is after Tauxe et al. (1983). Age of the Kuchinotsu Group has been determined based upon the fission track method of Okaguchi and Otsuka (1980).
Figure 8 Seismic reflection, gravity and magnetic anomaly profiles (L2) in the southernmost part of the Okinawa Trough. Location is shown in Figure 2. (γ) magnetic and (mgal) gravity anomalies (Ishihara and Murakami, 1976). The arrow shows the Central Graben; CP, Central pinacle (volcanic intrusion; Yonaguni Knoll, Kimura, 1983b)
Figure 9 Major Pleistocene fault and rift systems related to the formation of the Okinawa Trough. Legend 1, Central Graben; 2, fault, hatching on the down thrown side; 3, buried fault; 4, trench; 5, anticline; 6, syncline
Figure 10. Pleistocene tectonic framework of the Okinawa Trough. Legend 1, Central Graben; 2, basin occupied by Pleistocene igneous intrusions; 3, major fault and fault scarp; 4, buried major fault or fault scarp; 5, eastern boundary of the Ryukyu Ridge; 6, trench; 7, active volcanoes; 8, submarine intrusions or volcanoes estimated since Late Pleistocene time. Tectonic provinces can be distinguished by tectonomorphological similarities from the west to the east as: (I) Tunghai Shelf; (II) Tunghai Slope (western rifted margin); (III) Okinawa Trough; (IV) Tokara Ridge (eastern rifted margin); (V) Ryukyu Ridge.
Figure 11 Multi-channel seismic reflection profile (A) crossing Yokogansone Bank. Location is shown in Figure 2. Layer C fills the northern part of the middle Okinawa Trough. Thick double bar shows the portion drilled by TO-KA-1 (Figure 4). The arrow represents the Central Graben. ($\gamma$) Magnetic anomaly, (mgal) gravity anomalies. Notation of strata are given in Table 1. 'Sec' represents two way travel time.
intra Layer B₂ and A/B unconformities occur only on the Ryukyu Ridge. The C/D unconformity is of Late Miocene age in the Ryukyu Ridge. It is found not only in the Tokara Ridge but also in the arc-trench gap, and the Tunghai Shelf. The unconformity estimated to be of Middle to Late Miocene age occurs well beyond the immediate Okinawa Trough region (Ishiwada, 1981). The unconformity proposed by Herman et al. (1978) in the southern Okinawa Trough in III zone is not found. However, it may correspond to the boundary reflector between Layers B₂ and B₁ which are conformable.

**Discussion**

The crustal structure of the Okinawa Trough based upon seismic refraction data is shown in Figure 13. Six units are denoted as U₁, U₂, U₃, U₃', U₄ and U₅ in the Okinawa Trough and in the areas surrounding the Okinawa Trough. Strict correlations between seismic reflection and refraction profiles are difficult to make but the following correlations are suggested: U₁ (1.7–3.2 km s⁻¹) may be mainly composed of Late Miocene to Recent semiconsolidated and unconsolidated sediments (Layer A + B + C); U₂ (3.5–4.4 km s⁻¹) may correlate with the Tertiary consolidated to semiconsolidated sedimentary rocks (Layer C, D and E); U₃ (4.5–6.2 km s⁻¹) with pre-Tertiary layers (Layer E and granitic or metamorphic continental layer); U₄ (6.4–6.9 km s⁻¹) with gabbroic rocks; and U₅ (8.2 km s⁻¹) with the mantle.

Lee et al. (1980) stated that the velocity of 4.8 km s⁻¹ observed at the uppermost part of U₃' in the southern Okinawa Trough (Figure 13B) is primarily Miocene rocks. This velocity in my view is too high to represent sedimentary rocks in this area. Late Miocene andesitic pyroclastics and lavas were drilled from the layer showing a velocity of 4.6 km s⁻¹ at TO-KA-1 (Nash, 1979b) in the trough (Figure 4). Therefore, the 4.8 km s⁻¹ layer is regarded as igneous rock and U₃' in Figure 14B is defined to include the whole 4.7–6.0 km s⁻¹ layer, showing intermediate to basaltic transitional velocities. The crustal cross-section compiled from the seismic refraction data (Figure 13B) shows that the transitional velocity layer thus defined exists beneath most of the width of the southern Okinawa Trough. As a result, sedimentary layers of mostly Layer B and its younger layers are thought to make direct contact with shallow basin in the southern Okinawa Trough basin. The crustal structure seems to be similar to that of the Mariana Trough which is a classic example of a back-arc basin (Karig, 1971). In the Mariana Trough, the 4.5–5.4 km s⁻¹ layer of average thickness 1 km is composed of volcanics, and is covered with surface sediments (2.0–3.0 km s⁻¹) (Bibee et al., 1980). The southern Okinawa Trough profile (Figure 13B) also shows that the high velocity layer of 4.7–5.8 km s⁻¹ (U₃') is covered with a low velocity layer of 1.8–3.0 km s⁻¹ (U₁) without the intermediate velocity layer of U₂ found in the northern Okinawa Trough. In addition to this evidence, the central basin of the southern Okinawa Trough lacks U₂ (3.5–4.4 km s⁻¹). The northern Middle Okinawa Trough well data (TO-KA-1) shows that the Okinawa Trough is filled by the Late Miocene to Early Pleistocene Shimajiri Group and its younger sediments (Figure 11). Multi-channel reflection profiling data show the seismic interval velocity of Layer C at TO-KA-1 as 3.5 km s⁻¹ (Nash, 1979b). Therefore, U₂ in Figure 13A in the northern Okinawa Trough is thought to include the Shimajiri Group (Layer C) and its admixture with volcanics. This means that formations older than Layer B may be lacking beneath the southern Okinawa Trough basin.
Figure 13. Crustal cross-sections compiled from sonobuoy and two-ship refraction data. Numerals in crustal sections represent the crustal sonic velocity (km s⁻¹). Locations are shown in Figure 4. Tectonomorphic divisions (I to V) are shown in Figure 11. (A) Northern Okinawa Trough area, (B) Southern Okinawa Trough area. St. 31-32 are based upon data by Lee et al. (1980)
Sedimentary Layer B in the southern Okinawa Trough basin can be divided into two parts; the upper ($B_2$) and the lower ($B_1$) sequence. Though Layer $B_1$ pinches out towards the central axis of the trough (Figure 14), Layer $B_2$ conformably overlies Layer $B_1$ and is seen to be slightly offset by normal faults at the Central Graben. This suggests that the spreading of the trough may have occurred during the deposition of Layer $B_1$ in the basin (Figure 15) and that the spreading became very slow or stopped during the deposition of $B_2$ and later sediments. This evolution explains the lack of Layer $C$ in the southern Okinawa Trough basin. Correlation between the seismic reflection record and seismic refraction result leads to the interpretation that the Early Pleistocene layer (Layer $B_1$) is in contact with basalt formed by young spreading produced basalt; strongly suggesting that spreading has occurred since about 2 Ma (Table 1). In the southern Okinawa Trough linear magnetic anomalies have been found by Lee et al. (1980). Our data seem to show that the magnetic anomaly pattern of $L_2$ in Figures 8 and 16 correlates with the magnetic reversal time scale since 1.9 Ma (Kimura et al., 1985). However, other magnetic profiles in the southern Okinawa Trough in Figure 16 ($L_3$, $L_6$, $L_7$, $L_8$, and $L_{11}$) lack the peak corresponding to the Brunhes Normal Epoch except $L_9$. Therefore, it may be suggested that the central parts of the southern Okinawa Trough spread from the Oldvai Event to just before the Brunhes Epoch, and spreading has restarted in the Brunhes Epoch only at the northern and southernmost part of the southern Okinawa Trough (Figure 16). This is in the right relation to mode of sedimentation in Layers $B_1$ and $B_2$. Therefore, two main periods of extension are recognized.

Two groups of ages of volcanic rocks were obtained from the middle Okinawa Trough. One is a group of rhyolite and basalt which has been dredged from the seamount at St. 398 in Figures 4 and 6. The rhyolite has been dated as 0.79 ± 0.39 Ma (Shibata et al., 1984). Another is that of dacite, andesite and basalt which are younger than 0.4 Ma (Kaneoka et al., 1985) (St. S and D-6 in Figure 4). Taken together, this geological evidence shows two main periods of extrusion of magmas such as one between 1.9 and 0.8 Ma and another since 0.4 Ma. Figure 17 shows magnetic profiles from this region projected to 340°, the perpendicular direction to the Central Grabens in the northern Okinawa Trough. These show that the otherwise generally narrow sharp central anomaly is superimposed on low-amplitude anomaly profiles. This axial anomaly coincides with the most recent igneous intrusion (olivine basalt) (St. D-1 and D-6 in Figure 4). The Central Graben could coincide with a central magnetic anomaly of a normal event (Figure 17).

Herman et al. (1976) considered that back-arc spreading in the Okinawa Trough initiated sometime after Late Miocene-Early Pliocene time (during the deposition of their Unit B), and that the Ryukyu Arc was rifted from the continental margin. They concluded that the rate of spreading in the southern Okinawa Trough changed to only a few mm yr$^{-1}$ at the time corresponding to their unconformity between their Units A and B, because Unit B is deformed and was probably deposited in the basin before the major period of spreading ceased. In contrast, Unit A is not deformed except in the Central Grabens. Though the
Figure 15 Model showing relationship between sea-floor spreading and mode of sedimentation of Layer B1. Black and white basement represents new crusts formed in the normal and reversal magnetic polarization time.

Boundary separating their Unit A from Unit B cannot be regarded as an angular unconformity in the present study, their conclusion is the same as that of this paper if their Unit B correlates with Layer B1, Herman et al. (1978) stated that the spreading speed slowed before the deposition of Unit A (Layers B2 and A in the present paper). However, the sedimentary structure of Layer B2 shows that the spreading practically ceased during the deposition of Layer B1. It seems that the activity reforming the Central Graben started in Late Pleistocene. Lee et al. (1980) concluded that crustal separation (spreading) started in Pliocene time and has continued to the present; they considered that the trough basin is filled by Pliocene to Recent sediments, and that the Central Grabens offset those sediments. In my view, the axial zone of the southern Okinawa Trough, at least 40 km wide, lacks the 3.5 km s⁻¹ layer (U2, including Pliocene Shimajiri Group, Layer C) and Layer B1 is regarded to cover the young basaltic layer directly as stated previously. On this basis, it would seem that crustal separation in the axial zone has been occurring only since 1.9 Ma. Average half spreading rate is estimated as about 2 cm yr⁻¹.

Tectonic development

The regional tectonic development has been discussed by Letouzey and Kimura (1985). Therefore, this discussion is focused only on the development of the Okinawa Trough, referring to Table 1. The first erosional crustal thinning may have been occurring since at least Oligocene time. A large Oligocene regional unconformity is known in the area surrounding the present Okinawa Trough (Table 1; Ishiwada, 1981). It is likely that doming of the crust occurred as a result of upriasing of the basaltic layer during Oligocene time, which caused the older sediments to be severely eroded, thereby producing the D/E unconformity. At this time, in contrast, thick sediments were deposited in the old Ryukyu Trench (Kimura, 1983). Due to the early extensional movement normal faulting may have developed in the upper part of the crust, and grabens may have formed in Early Miocene time. Then; sandstone and minor mudstone (Yaeyama and Sasebo Groups; Matsumoto, 1979) were deposited in these grabens and dacitic to andesitic Neogene igneous activity (so-called Green Tuff activity) occurred. The graben might have included at least a part of the eastern margin of the Taiwan-Sinzi folded zone (Emery et al., 1969; Wageman et al., 1970) on the Tunghai Shelf to the Ryukyu Ridge. After the deposition of Layer D, the crust was uplifted again to create the widespread C/D unconformity of Middle to Late Miocene time, possibly due to magmatic supply beneath the crust. Then Layer C was deposited, over-
lying the widespread C/D unconformity. At the end of the deposition of Layer C, in Late Pliocene to Early Pleistocene time, the crust was again uplifted, and continental, crustal rifting may have started. At that time, areas surrounding the trough were uplifted and shallow facies sediments were deposited in the surrounding areas of the Okinawa Trough. During Late Pliocene and Early Pleistocene time, while Layer B1 was being deposited in the trough basin and before the deposition of Layer B2, spreading may have occurred in the southern Okinawa Trough and major faults that define the Greater Okinawa Trough progressively developed and rifted crustal blocks tilted against the axis of the trough. Then spreading stopped and Layer B2 was deposited conformably or partly unconformably in the trough. During this stable period, the top of the Ryukyu Ridge was truncated by marine erosion and coral reefs were extensively developed to form the Ryukyu Limestone on the isolated Ryukyu Ridge.

During Middle to Late Pleistocene time, another uplift of the Ryukyu Ridge occurred and the unconformity was formed in the Ryukyu Group (Table 1). At this time spreading started again but only in the northern half and in some parts of the southern Okinawa Trough. This is suggested by the fact that the Central Grabens offset Layer B2 (Figure 7) and volcanics younger than 0.4 Ma intrude Layer B2 in many parts of the Central Grabens as shown in Figures 8 and 10. Since the start of the Late Pleistocene spreading, shallow-water foraminiferal sandstones and reeval limestone were formed on the Ryukyu Ridge. Subsequently, the newest faults offsetting Layer B2 in the trough basins and in the Ryukyu Ridge were formed.

This history shows two main periods of extension such as a Pleistocene phase between 2 and 0.5 Ma and the present day phase, and that the position of the uplifted centre of the Ryukyu Arc region before the formation of the Okinawa Trough was not on the Ryukyu Ridge but rather on the present back-arc Okinawa Trough. The Tokara Ridge and the Tunghai Slope regions are regarded as the flanks of the previously uplifted axial zone. The Quaternary island arc activity is located in the back-arc rift zone.

Conclusions

Stratigraphy of sediments, magnetic anomalies and the crustal structure of the Okinawa Trough show that the crustal separation started about 1.9 Ma and continued intermittently to Recent time in the southern Okinawa Trough. The width of the spreading was less than several tens of kilometres and the average half spreading rate was about 2 cm yr⁻¹ in the southern Okinawa Trough. New spreading or rifting occurred from 0.4 Ma to Recent time. Magmatic intrusions occurred in many parts along the Central Grabens in the whole Okinawa Trough. The Okinawa Trough is thought to be floored by a thinned and subsided continental crust except for the southern part, and then only rifting is seen on the surface of the northern most Okinawa Trough.

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Figure 17 Correlation of magnetic anomaly profiles in the northern Okinawa Trough (Kimura et al. 1985). Locations are shown in Figure 3

Marine and Petroleum Geology, 1985, Vol 2, August 239
Back-arc rifting in the Okinawa Trough: M. Kimura


Kimura, M. (1983b) Submarine Topography around Ryukyu Arc, Scale 1 : 180,000., 1 Sheet, Okinawa Times Company


