The Geological Development of the North Okinawa Trough Area from Neogene Times to Recent*

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Abstract: An interpretation is presented of the Neogene to Recent geological development of an offshore area, located at the northeast end of the Okinawa Trough. The interpretation is based on geophysical and well data obtained by Nishi Nihon and Shin Nishi Nihon Sekiyu Kaihatsu K.K. during exploration in their Tokara/Amami concession area.

Basin development, accompanied by widespread volcanism and strongly influenced by Pre-Tertiary basement structures, commenced in Late Neogene Times with the formation of the Okinawa Basin. Toward the end of the Neogene a further phase of basin formation and volcanism occurred which led to the development of the present day physiography.

1. Introduction

With few exceptions, Neogene formations represent the major target for hydrocarbon explorationists around Japan. All the main ingredients of the exploration play—source rock, reservoirs, structures etc—are found in formations of this age. However, despite, extensive geophysical studies (onshore and offshore), the drilling of over one hundred, offshore wells and a long history of onshore geological investigation, there still remain, for a variety of reasons, many fundamental problems regarding the geology of the Neogene Period.

In the area of Southwest Japan (Southwest Honshu, Shikoku, Kyushu and the Nansei Shoto (Ryukyu Islands)) these problems stem, largely, from the fact that Pre-Tertiary rocks outcrop mainly onland while all the main Neogene depocenters lie offshore, in lightly explored and geologically undescribed areas. As a contribution to the understanding of this area an interpretation is outlined here of Shin Nishi Nihon Sekiyu Kaihatsu K.K. (S.N.S.K.) Tokara/Amami concession area—a large, offshore, mining concession covering some 45,000 km², located at the northeast end of the Okinawa Trough (Fig. 1).

Fig. 1 Major geological elements of Southwest Japan

The interpretation is based on extensive geophysical data (inc. over 10,000 km. of multichannel seismic and 13,000 km. of aeromagnetic lines) acquired during the past six years of exploration activity. Important information on the prospectivity and geology of the area was obtained in 1978 with the drilling of TO-KA-1—the first exploration well in the Okinawa Trough, located some 120 km. NW of Amami O'shima (Fig. 2).

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2. Description of the Tokara/Amami Area

2.1 Regional and local setting

Four major physiographic provinces surround the Tokara/Amami Area (Fig. 1). The Tunghai, continental, Shelf and Ryukyu Arc system both correspond to relatively young, geological features formed during Quaternary Times (Wageman et al. 1970, Kagami et al. 1971). In contrast the present Seinan Japan Arc, to the north, and the Philippine Sea Plate, to the east, represent much older Pre-Neogene elements (Kimura 1972, Katsumata 1971).

The concession area is located at the northern end of the Ryukyu Arc System and is divided into two parts (Tokara and Amami) by volcanic islands of the North Ryukyu Volcanic Ridge. The Amami area lies at the extreme northern end of the Amami Trough which, in this area, is dissected laterally, by the Tokara Channel northeast of Amami O’shima. A line extending northwest from the Tokara Channel serves to conveniently divide Tokara into southern and northern areas. Water depths in the southern area usually exceed 500m. with an angular shaped 1000m. sub-marine contour defining the north east end of the Okinawa Trough, extending along the west and east side of Tokara. In the northern area water depths are typically less than 500m. and bathometric trends in the north east sector appear to form a continuation of topographic features in south west Honshu. However, on the western side of the area water depths increase to over 800m. towards the Danjo Basin.

2.2 Basin sub-division

Seismic profiles extending across the Tokara/Amami area toward the Tunghai Shelf reveal a series of buried Pre-Quaternary basins and ridges which are barely represented in the present day bathymetry. (Fig. 3 and 4).

The major feature is a broad basin—the Okinawa Basin (Fig. 5) which in the north is subdivided by a central ridge—the Tokara Ridge— into the Goto sub-basin to the west and the Tokara sub-basin. The Basin is bound to the northwest by the Goto Ridge and to the southeast by a broad zone of volcanics and deformed sedimentary rocks which are referred to here as the Proto-Ryukyu Ridge. A small sub-basin—Amami sub-basin—occurs within the Proto-Ryukyu Ridge.

The Tokara and Amami sub-basins are located in SNSK Tokara/Amami concession. Seismic sections across north Tokara clearly show the ridge–basin–ridge differentiation of this area (Fig. 3). Only thin sediments (0.5 secs) occur on the ridges and in the Amami Sub-basin, whereas thick sediment packages (greater than 2secs. thick), are located on the downthrown side of major growth faults, in the Tokara sub-basin. In south Tokara, the basin–ridge–basin pattern is less clear and a number of important similarities exist between this area and the Goto sub-basin on the west side of the Okinawa Basin. In both cases very thick, largely undisturbed, sediment packages are found (greater than 3 secs. thick) while prominent basement ridges (characteristic

Fig. 2 Main geological results of TO-KA-1
(for location see Fig. 3)
Fig. 3  Line drawings to illustrate stratigraphic and structural characteristics of the Tokara/Amami area
Fig. 4 Pre-Quaternary structure of the Tokara and Amami sub-basin

of the Tokara sub-basin) are more subdued. Sediments in the Goto sub-basin thicken toward the Tokara Ridge, in the north, and directly onlap the Goto Ridge to the west.

Northeastwards the Okinawa Basin passes into an area of thick volcanics (Late Neogene and Quaternary) in central Kyushu and minor fault-controlled sedimentary basins of the Setouchi Subsidence Zone (Huzita 1962) of Southeast Honshu (Fig. 5, Table 1). The southwestern extension of the Okinawa Basin is represented by a belt of thick sediment straddling the western margin of the Okinawa Trough (Honza 1976).

2.3 Stratigraphic Framework

From seismic sections across the Tokara sub-basin three major stratigraphic units are recognised on the basis of reflection character and structural disposition (Fig. 6). Ages assigned to the units are based on well data (Fig. 2) and regional geological information. Since direct seismic correlation into the Amami sub-basin cannot be made due to the intervening Quaternary volcanic ridge the stratigraphy of this area is described separately in section 2.3.2. In Table 1 the stratigraphic units defined in Tokara/Amami are integrated with rock sequences established in other parts of Southwest Japan.

2.3.1 Tokara sub-basin

a) Pre-Okinawa Basin Series (Pre-Miocene)

Throughout most of the Tokara area layered sequences are observed overlying a smooth-surfaced, acoustic basement (Fig. 3). Well data (Fig. 2) and extrapolation of land exposures offshore indicate that the basement rocks are composed of deformed Pre-Miocene sediments intruded by Middle Miocene and Pre-Tertiary granitic rocks.

b) Okinawa Basin Series (Upper Miocene—Intra Pleistocene)

Tilted and faulted, layered sequences representing the fill of the Pre-Quaternary Tokara sub-basin onlap acoustic basement. The upper boundary of this sequence is defined by a major, intra-Pleistocene, unconformity in north Tokara and its correlative equivalent in the south (Fig. 6). A prominent reflector of intra-Upper Pliocene age can be traced regionally throughout Tokara separating the whole sequence into an Upper and Lower Okinawa Basin Series. In TO-KA-1 this reflector occurs in a regressive sand and shale sequence and corresponds to the onset of marked shallowing in the well.
(i) Lower Okinawa Basin Series (Late Miocene—Late Pliocene)

In parts of Tokara, the Lower Series can be subdivided into a lower discontinuous unit—with an interweaving of short, strong and weak, reflections—and an overlying unit with a regular, layered character. Well data from TO-KA-1 indicates that this lower unit corresponds to Late Miocene pyroclastics and lavas (K/Ar: 6 m.yr.) unconformably overlain by a clastic sedimentary sequence.

(ii) Upper Okinawa Basin Series (Late Pliocene—Intra Pleistocene)

The Upper Okinawa Basin Series forms a regularly-layered sediment package interdigitated, in places, with highly diffracting volcanic (Ps.) horizons. The presence of a minor intraformational unconformity just above the main internal reflector and other local discordances between the two reflection packages indicate that tilting and faulting had commenced prior to the main movement in Quaternary Times.

Okinawa Basin Series in South Tokara
The Okinawa Basin Series in the south of Tokara differs in several important respects from that in the north (Fig. 4). In two basins on the western margin of the concession area thick packages of largely undisturbed, concordant reflections occur. The correlative equivalent of the intra-Pleistocene unconformity is a distinct, broad-band, basinwide reflector. The sequence below the reflector is subdivided into an upper unit, with strong continuous reflections and a lower unit, where reflection quality is poor and individual horizons are discontinuous. The clearly defined acoustic basement of the northern area is noticeably absent. The exceptional thickness of pre-Quaternary sediments in both areas implies either high sedimentation rates (>1km/10m.yr), achieved perhaps by sediment focusing into the deeper rifts of the initial basin, or a more prolonged period of sedimentation than that occurring in North Tokara (see sections 3.2.1 and 4).

c) Okinawa Trough Series (Intra-Pleistocene -Recent)

Above the intra-Pleistocene unconformity in north Tokara sediments exhibit a characteristic 'onlap fill' configuration (Mitchum et al. 1977). Only on the downthrown side of major growth faults and in the southern basins, do sediments of the Okinawa Trough Series concordantly overlie the lower formation. In the two southern basins this Series is divided into a thick, lower, slightly tilted, unit which is partly overlain by thin layers of sediment deposited since the formation of the present day Okinawa Trough.

2.3.2 Amami sub-basin

Only two major seismo-stratigraphic units can be identified, in the Amami sub-basin. The lower unit forms acoustic basement which is assumed to correspond to the deformed and intruded pre-Miocene sediments that outcrop along the Ryukyu Ridge. The basement is overlain by an undeformed sedimentary cover which is interbedded with volcanics. On the west side of the Amami sub-basin Quaternary igneous rocks of the North Ryukyu Volcanic Ridge extensively intrude and directly overlie the base ment rocks.

In a few places an unconformity can be distinguished within the cover sequence which is tentatively correlated with the intra-Pleistocene unconformity in North Tokara (re: 2.3.1). The unconformity divides the cover sequence into a thin, tilted Pre-Deformation Series(mainly Pliocene) and an overlying Post Deformation 'fill' Series. The latter which exhibits a pronounced 'tram line' reflection character accounts for the greater part of the total sediment package in Amami.

2.4 Structure

2.4.1 Description

The configuration of the Pre-Quaternary sub-basins provides an important clue to interpreting the geological development of the Tokara/Amami Area. The shape and structure of the two sub-basins, based on simplified isopach maps of the Lower Okinawa Basin

Fig. 6 Idealised seismo-stratigraphic relationships in Tokara
Series (Tokara sub-basin) and a widespread reflector just above acoustic basement in the Amami sub-basin, is illustrated on Fig. 4.

The Tokara sub-basin has a symmetrical, bow-shaped form which is convex, oceanward. The change in orientation of the basin axis (approximately 40°) occurs within a broad zone (Tokara Channel Zone—see Fig. 4) where individual depocentres are terminated abruptly against NW/SE trending fault-bound ridges. The gross structure of the Tokara sub-basin, in cross section, resembles that of a large half-graben (Fig. 3.a, b, c, and Fig. 4). A major listric shaped, growth fault (Tokara Line) can be traced continuously from the northern end of Tokara into the Tokara Channel Zone. The fault plane curves and flattens with depth and can still be recognised on many seismic lines below 5km. Collapse structures and sediment thickening indicate that the polarity of faulting was consistently downward, to the north-west. A similar, deep-seated, curved fault is recognized on sections in the south (Fig. 3. c, d, f) but it cannot be directly linked with the major fault in the north which appears to terminate against a NW/SE trending ridge in the Tokara Channel Zone.

The simple 'half-graben' structure of the Tokara sub-basin is complicated by a number of additional structural features. At the northern end of Tokara, for example, the main basin branches westward into a minor half graben which is, sinistrally, offset by a NW/SE trending fault.

A further modifying feature to the simple half graben configuration are trilete-shaped depocentres which appear to over print the underlying structure of the sub-basin (Fig. 4). Cloos 1939, Burke and Dewey 1972). The southern depocentre in the Amami sub-basin forms a particularly clear example of a trilete rift structure. Significantly, both the north and southwest limbs of the rift contain thick Upper Miocene—Upper Pliocene sediments whereas the southeast trending arm is undeveloped with only thin sediment cover overlying acoustic basement. A second, noteworthy example is found in north Tokara. The three arms of the rift, trending northeast, west and southeast, are all well developed although the southeast limb appears to be laterally displaced 10km. south. The most important feature of this rift, however, is the massive intrusive stock which lies close to the centre of the three arms and which, undoubtedly, is related to their origin.

2.4.2 Pre-Miocene Basement structures

The northern end of the Tokara Line lies directly along strike from the inferred extension of the Butsuzo Tectonic Line (Geological Survey of Japan 1976)—a major fault lying within a broad zone (100–200 km wide) of Pre-Miocene thrusting (Pre-Miocene Thrust Zone) in the Seinan Japan Arc (Fig. 5).

The structural extrapolation of this major tectonic feature into the Tokara area lends tangible support to earlier suggestions that the pre-Miocene framework of the Seinan Japan Arc continued into the East China Sea area (Koniishi 1965). The precise location of the Tokara Line to the south, beyond the Tokara Channel Zone, cannot be clearly decided on geophysical and geological data available at present. If the Tokara Line remains a discrete, continuous feature, southward (an uncertain assumption in view of the branching morphology of major faults in other parts of the Thrust Zone—see Fig. 5) it may be represented by one of the large northwest dipping faults in south Tokara that form the eastern margin of the Tokara sub-basin.

3. The Geological Development of the Tokara/Amami Area from Neogene Times to Recent.

3.1 Summary of Events

In this section the geological development of Tokara/Amami is discussed in the context of the regional evolution of Southwest Japan. A sequence of maps of Figure 7 (a–g) illustrate the Late Cenozoic evolution of the Tokara/Amami Area and the parallel development of other areas in Southwest Japan is shown on Table 1.

The Neogene to Recent geological history of the Tokara/Amami Area is broadly divisible into three main phases. An Early Neogene Phase, characterised by widespread uplift, was followed in Late Neogene and Quaternary Times by two, relatively short, phases of rifting and volcanism. The Late Neogene Phase was of major importance in shaping the area, involving the formation of depocentres (Tokara sub-basin) into which the greater part
of the total sediment package overlying acoustic basement, accumulated. This phase was followed in Pleistocene Times by movements (Quaternary Phase) that still continue to the present day and which formed the physiography of the Ryukyu Arc System.

3.2 The Early Neogene Phase

3.2.1 The Central Uplifted Zone of Southwest Japan (Table 1 (c))

Until Latest Miocene Times the Tokara/
Amami area formed part of a broad, uplifted zone (Central Uplifted Zone of Southwest Japan) composed of faulted and intruded Pre-Miocene sediments. The Zone, which extended from the 'backbone range' of Southwest Honshu to the present day site of the Ryukyu Arc System, was flanked by Shimanto, forearc basins to the east (Outer Basins on Table 1) and Early Neogene depocentres (Inner Basins on Table 1) to the west.

Within the Central Uplifted Zone isolated basins developed in the Setouchi area related to differential movements along major faults of the Pre-Miocene Thrust Zone (principally the Median Tectonic Line). An analogous type of basin development may have similarly occurred in the East China Sea where, throughout the Neogene, the inferred back-arc extension axes were orientated at a high angle to major basement faults (see section 4). Possible sites of local, Early Neogene sedimentation may be represented by the deep sedimentary basins in south Tokara and along the eastern margin of the Goto sub-basin (see section 2.3.1 and Fig. 7. a).

However, the age interpretation of layered sedimentary sequences, demonstrate, quite clearly, that the main phase of subsidence and fragmentation of the Central Uplifted Zone took place in Late Miocene Times, when movements associated with the Late Tertiary Tectono-Magmatic Event occurred (Table 1 (c)).

3.3 The Late Tertiary Tectono-Magmatic Event

In Late Miocene Times, basin formation occurred throughout the Central Uplifted Zone associated with intermediate to basic volcanism. Volcanics of this age, interbedded with Late Neogene sediments, overlie acoustic basement in the Tokara sub-basin (Fig. 6) and are also recognised in Kyushu (e.g. volcanics, S.W. of Oita), the Setouchi Basin (Setouchi Volcanic Series) and as for south as Kumejima in Okinawa Prefecture (Aradake Fm.). Throughout Southwest Japan the volcanism and associated basin formation represented the latest in a series of events which collectively are referred to, here, as the Late Tertiary Tectono-Magmatic Event. The Event which commenced with uplift in Middle Miocene Times (Kuroda and Matsumoto 1942) and granitic intrusion (Shibata 1968) of the former Shimanto forearc basins was followed in Miocene Times by uplift, of the Inner Basins (e.g. Fukue, Tsushima Basins—see A. Minami this volume) and the recommencement of forearc sedimentation (Shuto 1952) around Southwest Japan (Table 1 (c)). The Late Tertiary Event, which can be correlated with regional Late Miocene tectonic and magmatic activity in the Tohoku Arc (Dewa Disturbance—Fujii 1974) and Hokkaido (Final Phase of the Hidaka Orogeny—H. Mitadera pers. commun.) reflects a major phase of plate movement around Southwest Japan (see section 4).

3.4 Late Neogene Basin Development in the Tokara/Amami Area

The distribution and thickness of Late Neogene sediments in the Tokara and Amami sub-basins is shown on Fig. 7. (b) (Late Miocene—Late Pliocene) and 7(d) (Late Pliocene—Intra Pleistocene). The overall shape of the two sub-basins was largely governed by the distribution and orientation of Pre-Miocene basement faults. (section 2.4.2) Major subsidence took place along the Tokara Line forming a belt of small discrete basins. Other depocentres formed along subsidiary faults or in minor intrusional-related rifts which, in the case of the Amami sub-basin, were interlinked by earlier basement faults. (Fig. 4).

The predominance of half-graben structures and the seismic evidence of successive collapse on the down-thrown side of major faults (Fig. 3), demonstrates the extensional nature of the stress field which led to basin development in Tokara/Amami. The symmetrical configuration of the Tokara sub-basin and the orientation of the undeveloped rift-arm in south Amami (re: 2.4.1) suggest that subsidence was related to NW/SE extension orientated at a high angle to the pre-existing basement structures (e.g. Tokara Line, Amami-Kagoshima Line).

Comparison of Fig. 7(b) and 8(d) show that toward the end of Neogene Times the pattern of sedimentation had begun to change dramatically. This change was related to tectonic movements which signaled the commencement of the second, Quaternary Phase.

3.5 Quaternary Phase

The present physiography of the East
China Sea Area developed (Ryukyu Arc System, Tunghai Shelf etc.) largely as a result of tectonic movements during this period. Related movements also occurred in the Seinan Japan Arc and were responsible for extensive faulting and considerable vertical movements (Sugimura and Uyeda 1973).

The main contribution of the Quaternary Phase in the geological development of the Tokara/Amami Area lies, largely, in the formation of the North Ryukyu Volcanic Ridge which emerged between the two sub-basins. Early effects of this event, in Upper Pliocene Times, are recorded in the contraction and, in places, uplift of Late Neogene depocentres in north Tokara (Fig. 7(c)). In TOKA-1 shallowing commenced in earliest Upper Pliocene Times and was associated with the deposition of regressive units outbuilding from the rising volcanic ridge to the east.

Uplift culminated in a major Intra (Early) Quaternary tectonic movement, which produced widespread tilting and erosion of earlier sediments accompanied by basic volcanism (Fig. 7(c)). Only in the two southern basins did sedimentation continue through the Quaternary without a major break (Fig. 7(f)). The area of Quaternary volcanic activity in Tokara/Amami is closely confined to the shallow basement area lying between the sub-basins. The only notable exception occurs in the vicinity of the Tokara Channel Zone where volcanic vents spread north-westward in a line, controlled by basement fault.

In Late Pleistocene Times (?) a further tectonic movement occurred which led to the formation of the present day physiography (Fig. 7(g)). The Okinawa Trough (defined by the 1000m. submarine contour) partly overlies the earlier site of the two southern basins in Tokara although it is significant to note that, at present, the deepest part of the Trough, in Tokara, is located to the east in a shallow basement area where previously no major subsidence had occurred.

4. Late Cenozoic Basin Development and Plate Tectonics in Southwest Japan

An implicit aspect of the whole interpretation presented in this paper is the assumption that many of the major geological events on the Southwest Japan continental margin are genetically related to underthrusting by the Philippine Sea Plate.

The widespread geological activity in the East China Sea area from at least mid-Tertiary Times onward may be compared, in scale, to that recorded in the Tohoku Arc(N.E.Honsbu) (Sugimura and Uyeda 1973; Honza et. al. 1977) during the same period. What is more the activity of these two areas contrasts sharply with the cratonic behaviour of southwest Honshu. In plate tectonic terms these broad differences are accounted for by the orientation of the respective plate margins with regard to the movement direction of the Pacific Plate. Since Late Eocene Times the dominant of the Pacific Plate has been westward (Morgan 1972) as a consequence of which north-south trending plate boundaries are underthrust (e. g. continental-oceanic boundaries, e. g. Tohoku Arc; oceanic-oceanic boundaries [transform fault], e. g. Izu-Bonin-Marianas Arc) initiating back-arc spreading. On the other hand plate boundaries sub-parallel to the movement direction (e. g. Southwest Honshu) remained stable blocks with only minor subsidence.

This simple kinematic model has two interesting implications with regard to regional basin development in Southwest Japan. Firstly, the general correlation between the different levels of geological activity with respect to the angular relationship between plate margins and the direction of underthrusting lends some support to the suggestion that thick sediments in South Tokara and the Goto sub-basin may reflect an extended period of subsidence along major basement faults (Pre-Miocene Thrust Zone) rather than simply high, Late Neogene sedimentation rates. (see section 2.3.1 and 3.2.1). Secondly, the model leads to a comparison of the geological development of the northeast Honshu (Tohoku Arc) and the East China Sea area in Late Cenozoic Times. However, while similarities do exist (for instance, a contemporaneous Late Tertiary Tectono-Magmatic Event in the Funakawa and Kitaura Ages) significant differences are also recognized (e.g. the extent and intensity of early Neogene volcanism and the landward migration of geological elements) which must be accredited to the different plate setting of
the two areas (Uyeda and Miyashiro 1974).

Details of the Late Cenozoic evolution of the Philippine Plate have still not been firmly established. The main disagreement centres around the formation of the Shikoku-Paracel Vela basin. One widely accepted interpretation of geomagnetic anomalies in the Philippine Sea proposes that the main phase of Late Cenozoic spreading took place in Early Neogene Times contemporaneous with movements in the Japan Sea (Kobayashi and Isezaki 1976). More recently, however, Murauchi and Asanuma (1978) proposed a two-stage model involving an Early Miocene (24–20 m.yr.) and Late Miocene (12–6 m.yr.) phase of opening. The association in time of various geological phenomena around Southwest Japan such as granodiorite intrusion, volcanism and back-arc basin formation (see section 3.3) imply a phase of major underthrusting which may correspond to the second stage of spreading in the Murauchi and Asanuma model.

Even though many uncertainties exist with regard to establishing this type of relationship between the geohistories of the oceanic and continental areas (e.g. the influence of contemporaneous back-arc spreading in Japan Sea, consequences of collision and subduction of sub-continental blocks) it is essential that the restraints which either area places on the other are seriously considered. By a joint geological evaluation of the two areas advances can be made toward developing an 'all-embracing' model for the evolution of Southwest Japan in Late Cenozoic Times.

5. Conclusions

The Late Cenozoic development of the Tokara-Amami Area (northeast end of the Okinawa Trough) was greatly influenced by Pre-Miocene basement structures and the effects of the Late Miocene Tectono-Magmatic Event.

Up to Late Miocene Times the area formed part of a broad uplift zone with only local sedimentation along subsiding fault blocks.

Extensional movements, associated with volcanism, led, in Late Miocene Times, to the formation of the Tokara and Amami sub-basin along Pre-Miocene tectonic lines and minor, intrusion-related (Miocene) rifts. In Latest Pliocene Times sedimentation in north Tokara decreased dramatically as the main centre of subsidence shifted southwards. Further tectonic movements and volcanism in the Quaternary formed the physiography of the present day Ryukyu Arc System.

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(要 旨)

新第三紀～現世の沖縄海盆北部の地質構造遍歴史

D. F. ナッシュ

沖縄海盆北部のトカラ・奄美地域の新生代後期の地質構造は、先第三紀基盤構造と中新世後期の構造変化に支配されている。この地域は中新世後期まで広域的な隆起帯により形成され、堆積は断層地塊の沈降域に限っておこなわれていたにすぎなかった。トカラ・奄美堆積盆地は中新世後期に、先第三紀基盤の構造線と貫入岩(中新世)に関連したリフト帯に沿う地域に堆積活動を伴う伸張性運動によって形成された。鮮新世後期には沈降地域の中心は南部に移動し、北部トカラ地域での堆積は減少した。現在の琉球列島区の地形はその後に引き続き第四紀の構造運動と火成活動によって形成された。