LAND CONNECTIONS BETWEEN EURASIAN CONTINENT AND JAPANESE ISLANDS - RELATED TO HUMAN MIGRATION

by

Prof. Dr. Masaaki Kimura

Summary

Recent submarine, geological, and geophysical investigations including diving surveys reveal the geo-history of the Japanese islands with special reference to Ryukyu Islands and the East China Sea. Three stages are fundamentally distinguished for formation process of the Ryukyu Arc and connections from the Japanese islands to the Eurasian continent. Around 7.0-5.0 Ma, the southwestern part of Japanese Islands (Ryukyu Arc) was a part of Eurasian continent. This is the first stage of land connection between the continent and Japanese islands. Then, sea areas invaded the continent to make a separated Ryukyu Arc. In the second land connection stage between 2.0 - 1.3 Ma the East China Sea area, including most of the Okinawa Trough, may have been subaerial. At that time, the Ryukyu Arc region may have been a part of the Eurasian continent. At 0.2-0.015Ma the third stage occurred and the Ryukyu Arc probably was connected to the Chinese continent, through Taiwan as a land bridge. The paleo-land probably was submerged step by step since 0.02 Ma caused by both of the crustal movement and the sea level rising after the last Ice Age. Submarine stalactite caverns were discovered at 10 - 35 m deep off the Ryukyu Islands. The caverns have subsided since the Würm (Wisconsin) Ice Age. Stone tools were also recovered inside one of them. Additionally, archeological ruins similar to an ancient castle, estimated at about 10,000 years were discovered beneath the sea off Yonaguni Island. Existence of Holocene and such submarine ruins provide indicators of subsidence processes of the Ryukyu Arc during post Glacial sea level rising.

Research data

IN RECENT years, submarine, geological, and geophysical investigations have been carried out in the Ryukyu Arc region, the western part of Japanese Arc by multiple international organizations (e.g., Kimura, 1985a,b, 1996a, b; Japanese DELP Research Group on Back-Arc Basins, 1991; Sibuet et al., 1987, 1999). The Ryukyu Arc (Fig. 1) lies near the eastern margin of Eurasian continent. This paper attempts to compile all available data obtained by those researchers and discusses land connections from the Eurasian continent to the Japanese islands. Seismic reflection profiles of single and multi-channel systems were used for the present study to clarify geological and stratigraphic sequence in the study area (Fig.2).

Dredging and drilling data were also incorporated to determine the stratigraphy in the studied area. Detailed topographic data collected with multi-narrow beam, manned and unmanned submersibles, and seismic refraction experiments were also available to study the geologic and geophysical characteristics in Japanese Arc area. Adding to this, SCUBA diving surveys around the Ryukyu Islands are available to know a detail submarine topography and geology.

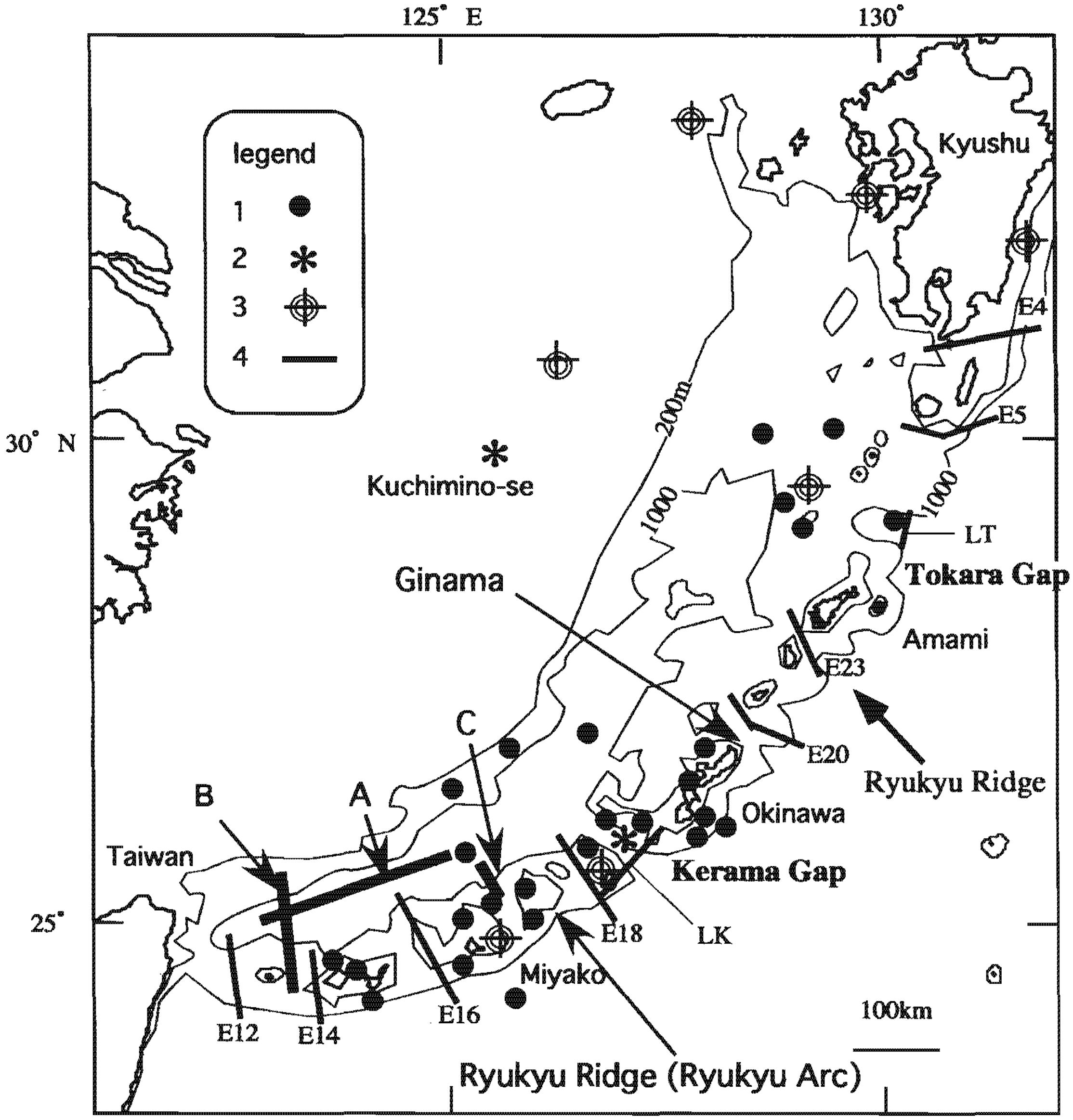
Morphology and tectonic framework of the Ryukyu Arc

The morpho-tectonic framework in the study region can be defined from west to east namely I) Tunghai Shelf, II) Tunghai Slope (western rifted margin of the Okinawa Trough), III) Okinawa Trough, IV) Tokara Belt (eastern rifted margin of the Okinawa Trough), V) Ryukyu Ridge, VI) Arc-trench gap and, VII) Nansei-shoto Trench (Ryukyu Trench). The Ryukyu Arc includes the Tokara Belt (IV) and the Ryukyu Ridge (V) (Kimura, 1996). The width of the present Okinawa Trough is about 100 - 150 km. The topography of the Tunghai Slope and Tokara Belt is rough, and both features are regarded as rifted margins of the Okinawa Trough. Active volcanism is recognized in the volcanic front of the Tokara Belt. Active rift movement associated with classic graben was identified in the middle and southern part of the Tokara Belt (Kimura *et al.*, 1975; Sibuet *et al.*, 1998). Deep faults, such as the Ryukyu Ridge Fault and the Tunghai Shelf Fault were generated in the early Pleistocene along boundaries of morpho-tectonic division.

THE OKINAWA Trough is a back-arc basin that has developed generally parallel to the Ryukyu Arc. The Okinawa Trough is estimated to be filled with deposits since late Miocene time and the central grabens or rifts develop along the axial part of the trough arranged in an echelon formation. The central graben was first found by Kimura *et al.* (1975) in the middle Okinawa Trough area. Intrusive bodies exist beneath the central grabens to form basal highs in many cases that define the central graben as the most recent fissure originating in response to magma uprising. Many active hydrothermal spots including black smokers have been found since 1986 in the Torishima Rift (Ensei knoll), Iheya Rift, and Aguni Rift (Izena Hole) in the middle Okinawa Trough (Kimura *et al.*, 1988, 1989, 1991; Nakamura *et al*, 1990; Halback *et al.*, 1989).

Crustal structure and geostratigraphic sequence

Seismic refraction experiments using explosives have been carried out more than four times since 1984. Before that, there were few lines crossing the Ryukyu Arc and the Okinawa Trough. There are many sites of sono-radio buoy experiments. All of the seismic refraction data show a similar picture of the crustal structure of the Okinawa



1. Limestone, 2. Fossil mammal, 3. Drill site, 4. Sparker line

Figure 1: Submarine topography around the Ryukyu Arc. E4-12 represent sonic survey lines by means of sparker (30.000 joule). LT and LK shows track lines by diving surveys using with "Shinkai 2000". Lines A, B and C represent locations of Profiles in Fig.2.

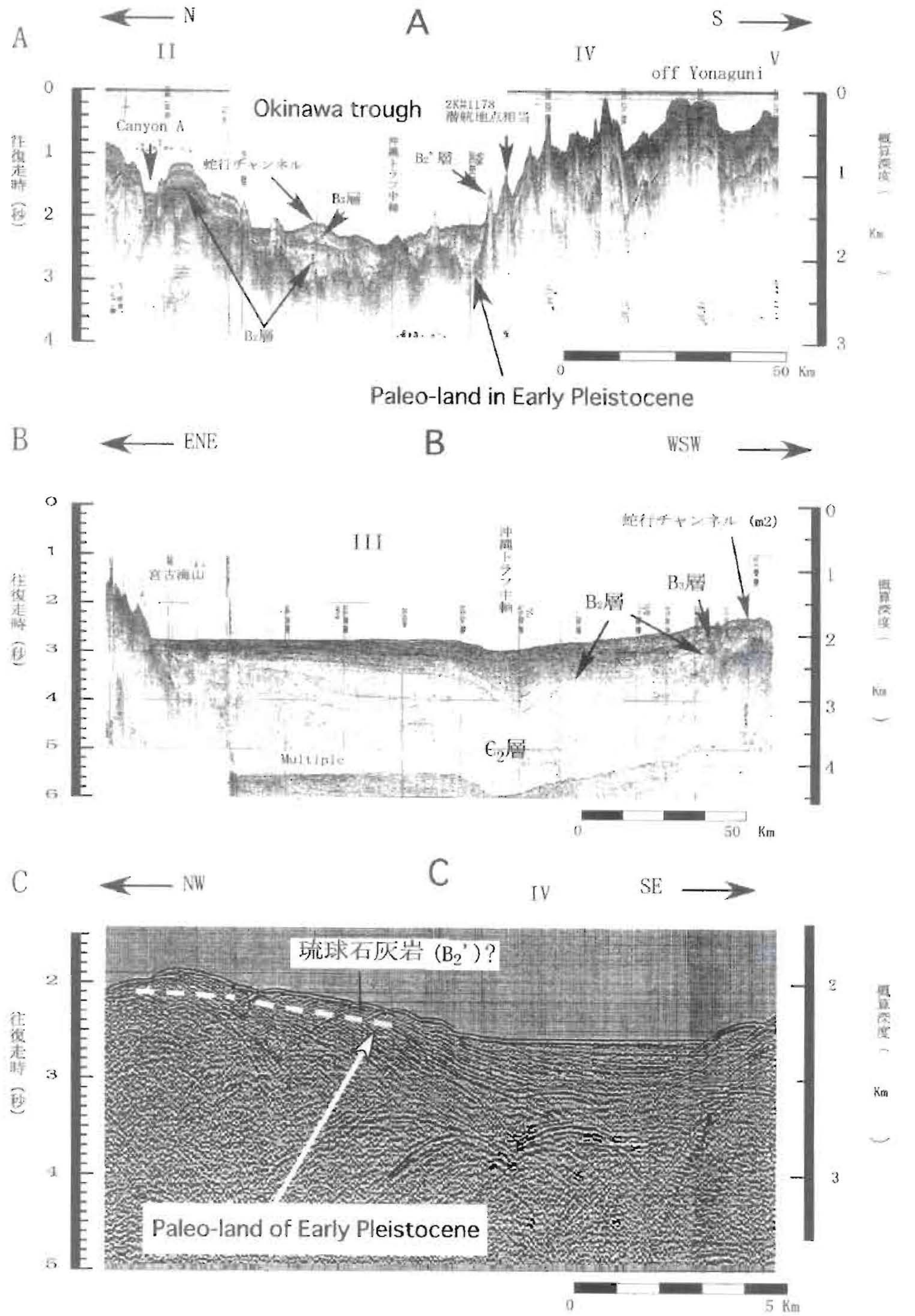


Figure 2: Sonic profiles showing some unconformities (paleo-lands) since Early Pleistocene. Locations are shown in Fig. 1. A and B: Single channel air gunning; C: Multi channel air gunning profile.

Trough from north to south. The depth of the Moho Discontinuity varies 25 - 16 km from north to south (Iwasaki *et al.*, 1987; Hirata *et al.*, 1991) and there is no variation from east to west. Chemical analysis of major-and rare-earth elements collected from the Central Rifts of the Okinawa Trough, and those in other portion of the Trough, show island-arc affinity. There are no magnetic anomalies in the Okinawa Trough, indicating that there is no oceanic crust underlying the Trough (Sibuet *et al.*, 1987,1988). Gravity anomalies also indicate that the Okinawa Trough is comparable to a continental crust. These data indicate that there is no oceanic crust beneath the entire Okinawa Trough.

Based on detailed velocity structure in the southern Okinawa Trough: the layer of 7.5 km/s is correlated with that of the mantle and the layer of 6.2 - 6.4 km/s with the layer 2 and the 4.5 - 6.0 km/s layer is correlated with granitic layer (Hirata *et al.*, 1991). The thickness of the 4.5 - 6.0 km/s and 6.2-6.4 km/s layers decreases remarkably beneath the trough that suggests that crustal stretching occurred after the formation of the 4.5 - 6.0 km/s layer. The 3.6 - 3.9 km/s layer appears to be correlated with the Yaeyama Group of the early Miocene, based upon the stratigraphic sequence and sonic velocity. The 3.0 - 3.5 km/s layer appears to be correlated with late Miocene strata on the basis of seismic reflection records and drilling data (Marutani and Sato, 1985). The 1.8 - 1.9 km/s layer is correlated with early Pliocene to early Pleistocene sediment, such as the upper Shimajiri Group and Quaternary sediments (Table 1).

SEISMIC reflection profiles reveal a deep sedimentary basin resembling a big trough beneath the Tunghai Slope, and the sedimentary layer in the basin shows that about 6 km thick (Marutani and Sato, 1985; Kimura, 1985a, b; Letouzey and Kimura, 1986). This trough is tentatively called older Okinawa Trough. Thus, there are two sedimentary basins such as an older and a younger Okinawa Troughs in the northern half of the backarc basin. In the southern part, a younger one seems to be coincident with the older one.

Geohistory

DRILLING DATA from a Japanese oil company show that there are Pliocene to Pleistocene sediments of 2,490 m thick in the northern-most part of the Okinawa Trough, for which the lower part is correlated with the Shimajiri Group, and the upper part is correlated with Layers B_1 and B_2 (Ryukyu Group), table 1. A thick B_1 layer is expected in the central part of the Okinawa Trough as pounding sediment estimated as non-marine sediment. The sedimentary basin may have an expanded origin controlled by the clockwise rotation of the Ryukyu Arc since 1.7 Ma. The Beppu-Shimabara Graben in central Kyushu has been active since 1.7 Ma, accompanied by extensive volcanism, and faulting. The Kuchinotsu Group□Okaguchi and Otsuka, 1980□ was deposited in the graben, formed at that time. Contemporaneously, the margin of the central basin of the Okinawa Trough was eroded sub aerially from 1.7 - 1.3 Ma, as shown by the unconformity under Layer B_2 in the Tokara Belt.

Subsiding the Okinawa Trough was accelerated from 1.3 Ma and the shape of the Ryukyu Ridge was clearly formed. Sea level became relatively high, and the Ryukyu Limestone deposited at the Philippine Sea side from 1.3 - 1.0 Ma. The Greater Okinawa Trough has been formed since 1 Ma. Since then, rifting in the central graben of the Great Okinawa Trough has developed.

Available data confirm evidence of volcanic activities in the central rift valley in the middle Okinawa Trough (Kimura *et al.*, 1986). Potassium-Argon (K/Ar) dates of volcanic rocks composed mostly of high

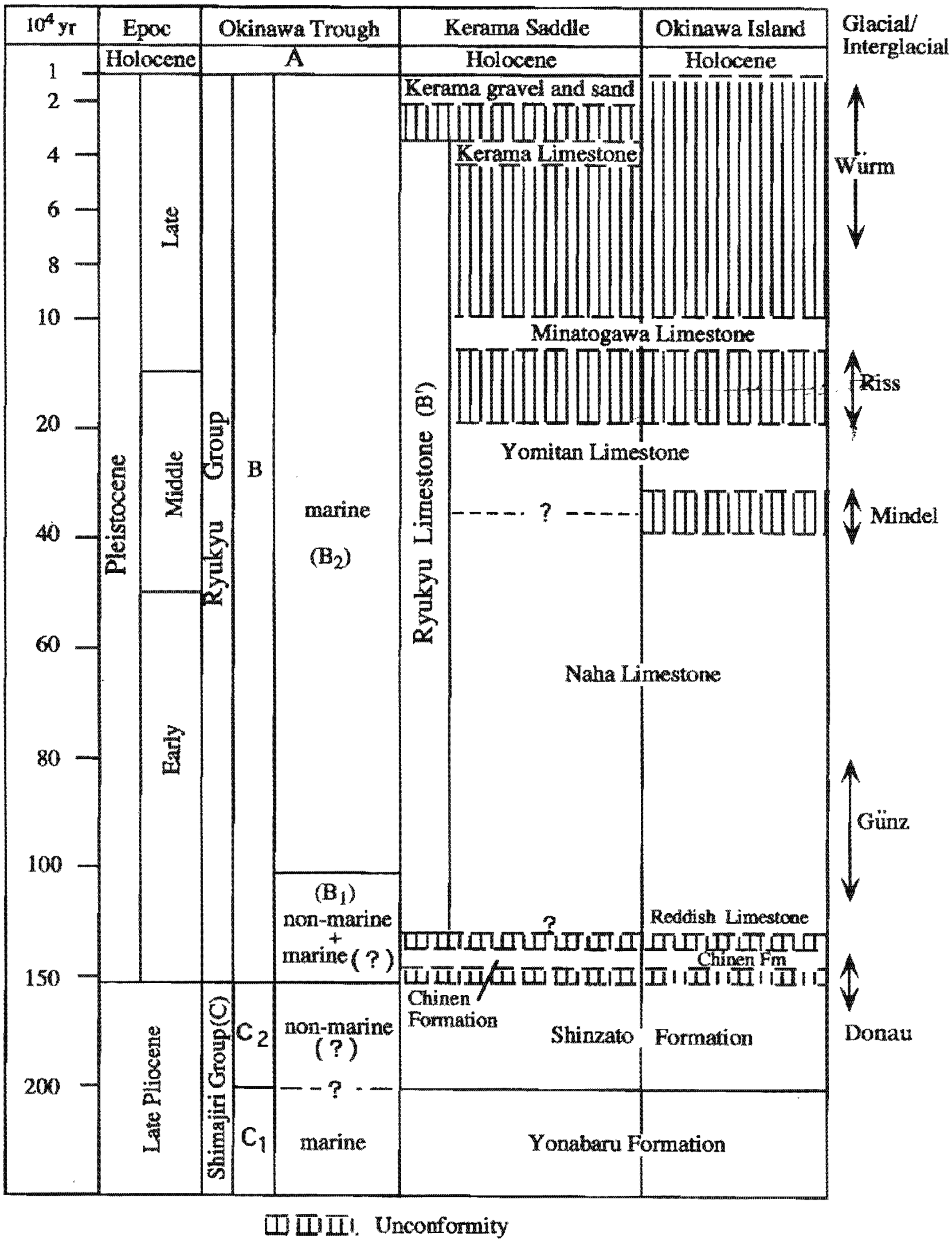


Table 1: Geology and stratigraphic correlation table in the Ryukyu Arc region after Kimura (2002b) and Otsuka and Takahashi (2000).

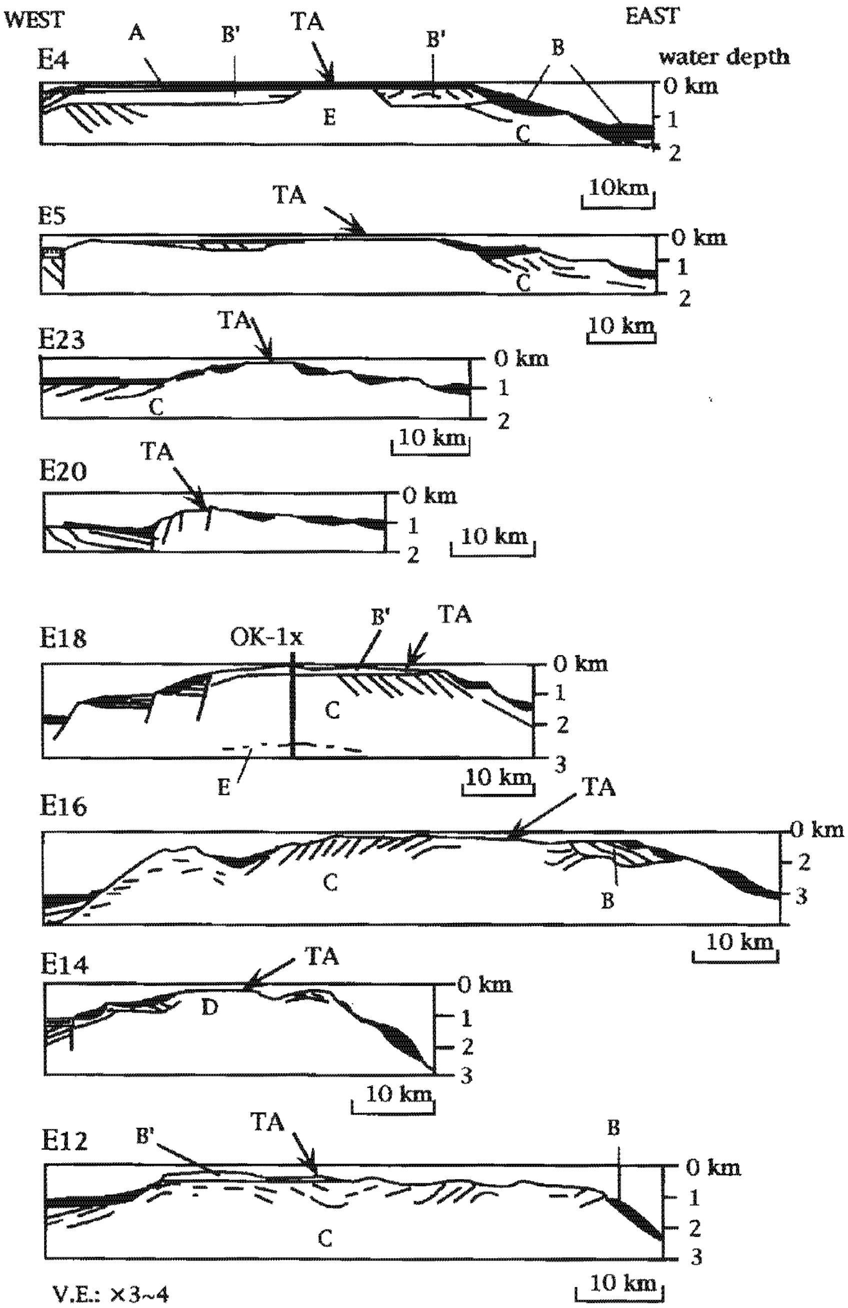


Figure 3: Interpreted cross section using sparker profiles (30.000 joules) right angle to the Ryukyu Ridge showing TA (Terrace A). Locations of E4 – E12 are showing in Fig.5. A-E are explained in Fig.4 OK-1x: drilling site of the Tokara (LT) and Kerama Gaps (LK). Locations of LT and LK are shown in Fig.5.OK-1x: Drilling site. Numbers represent sample numbers (after Kimura, 1996b).

alumina basalt and decide represent activities younger than 0.5 Ma, (Kimura *et al.*, 1986). Some of the central knolls as like as hills in the rift valley revealed active hydrothermal mounds ("SHINKAI 2000" Research Group on the Okinawa Trough, 1986). Furthermore, black smokers were found at Izena Hole in the middle Okinawa Trough (e.g., Nakamura *et al.*, 1990).

Land connection during late Pleistocene time

THERE EXISTS a very long, flat terrace on the summit through the entire Ryukyu Ridge: cross sections of this terrace (Fig. 3) show essentially the same features, such as uncovered soft sediments on the top and thick sedimentary coverage of side slopes of the terrace, despite surface depths varying from 100 - 500 m as shown in Figures 6 and 7. This terrace is named Terrace A (TA). Based on seismic reflection surveys, for both single and multi-channel, the TA is offset by normal faults, thus its depth varies from 100 m to more than 1,000 m in the Tokara and Kerama Gaps as shown in profiles.

Exposures of bedrocks are widely recognized broadly along the uppermost surface of TA in the Kerama and Tokara Gaps, as observed by "SHINKAI 2000", "Nagasaki Maru" and others. Outcrops of bedrock continue from the shallow depth to 100 m deep, suggesting that less depositional time occurred for newer sediments after the erosion of the TA surface. Thus, the flat plane of Terrace A (TA) is identified as the erosional surface of post-formation Ryukyu Limestone in the late Pleistocene from 0.2 - 0.02 Ma (Kimura *et al.*, 1992; 1994; 1996b). As a result, TA has been offset by normal faults from 100 m to over 1,000 m depths, based on the sonic profiles. Both TA shallows and TA depths are identified as the same erosional surface.

Ryukyu Limestone composing the bedrock that was recovered from a flat terrace at 935 m in the Kerama Gap was dated using nanno fossils. The age of the limestone was estimated as younger than 0.27 Ma. The age of the fossil bivalve *Amusium japonicum* (Tsukihi-gai in Japanese) in the same limestone sample was dated with Election Spin Resonance (ESR) method, providing an age of 0.24 Ma or younger. Based on these dates, it was inferred that this area was sub aerially eroded after 0.24 Ma at least since 0.2 Ma. From the summit of the Ryukyu Ridge in the Kerama Gap (Kerama Saddle), calcareous sediment (Kerama Limestone) of about 30,000-40,000years old was collected. The Kerama Limestone covers the Naha Limestone without uniformity, suggesting that this level was dry land from 0.2 - 0.04 Ma. Normal sandy sediments covered the Kerama Limestone with unconformity. Samples of this sandstone were collected abundantly from a depth between 500 - 600 m in the Kerama Gap using "SHINKAI 2000". The sandstone covers the erosional bedrock broadly with unconformity. The ^{14}C age yielded an accelerator mass spectrometry (AMS) date of about 25,000 years of normal sediments coating Ryukyu Limestone cropped out on the flat plane TA.

ON THIS ACCOUNT, the level TA is estimated to have fundamentally dry land sometime between 0.2 - 0.03 Ma. Additionally, a mammalian fossil bone tooth was recovered by "SHINKAI 2000" on the flat surface of TA in the Kerama Gap at 620 m depth. The bone tooth has been identified as belong to Proboscider (or fossil elephants). Its age could not be dated because of lack of collagen, but is believed to date too younger than 0.2 Ma, probably 40,000 - 30,000 years ago. This suggests that the land bridge continuing to the continent existed around this time as well, because a large-bodied mammal could have arrived only by crossing a land bridge (Kimura, 1996 b, c).

From Peifu Channel of the Taiwan Straits, abundant fossil land mammals, namely elephants, deer, and cows were recovered

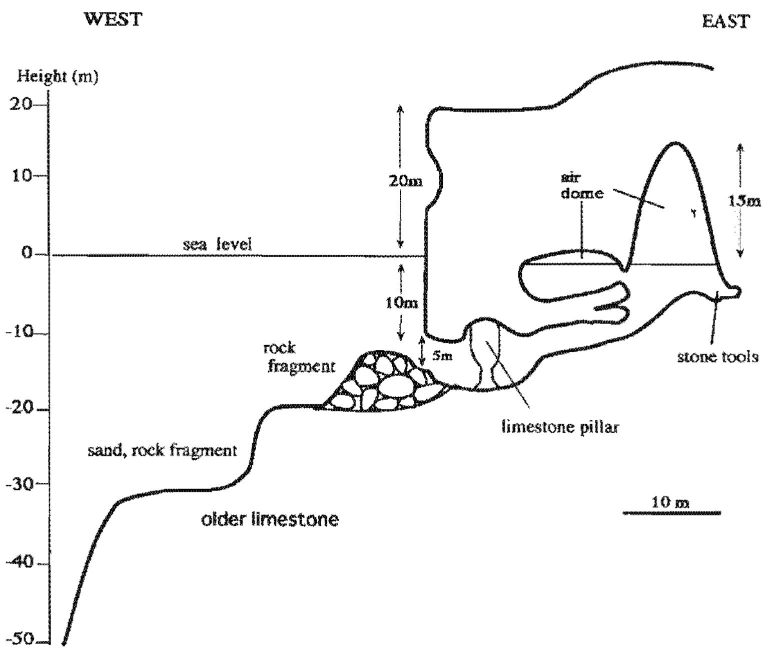


Figure 4: Cross section of Ginama Submarine Stalactite Cavern off the northern-most part of Okinawa-Jima Island (after Kimura, 1997). Location marked by the star in Fig.1.

from the bottomof the sea at depths of 120-140 m deep at the central part of the strait. ^{14}C measurement of samples yielded ages of 19,980 ± 200 □ 15,940 ± 200 Yr bp. Such values are close to the age of the Wurm glacial maximum, and there are fossils that may be older (Nakamura et al., 1996). On the others, a lot of different mammalian fossils considered to have come from the continent to Nansei-Shoto Islands in the late Pleistocene were excavated on the land (Oshiro and Nohara, 1990; Hasegawa, 1980).

EXPOSURE OF the basement rock Shimanto Terrane dating to 100 Ma, was also identified by diving investigations of "Dolphin 3K" in the Tokara Gap to the north. Subsequently, an extensive outcrop of Ryukyu Limestone was discovered by the diving investigation of "SHINKAI 2000" in the Tokara Gap. Ryukyu Limestone was recovered from practically the deepest part of the Gap near 1,200 m. Age of this limestone dated to 0.45 - 0.4 Ma, by ESR (Kimura, 1997). The surface of this limestone bed is eroded and the surface is correlatable with TA on the Ryukyu Ridge. It is covered with normal, sandy sediment that is younger than 0.03 Ma (Table 1). It is possible that there was sub aerial erosion sometime between 0.4-0.03 Ma.

Tunghai Continental Shelf, deeper than 100 m, was under erosional conditions during the Wurm Glacial Age, based on analysis of sonic survey records. The present continental shelf, shallower than 130 m suffered from erosion during the Würm Age (Nasu, 1990), although it is not known whether seawater changes contributed to the formation of the current continental shelf then or before the Würm. Fossil deer

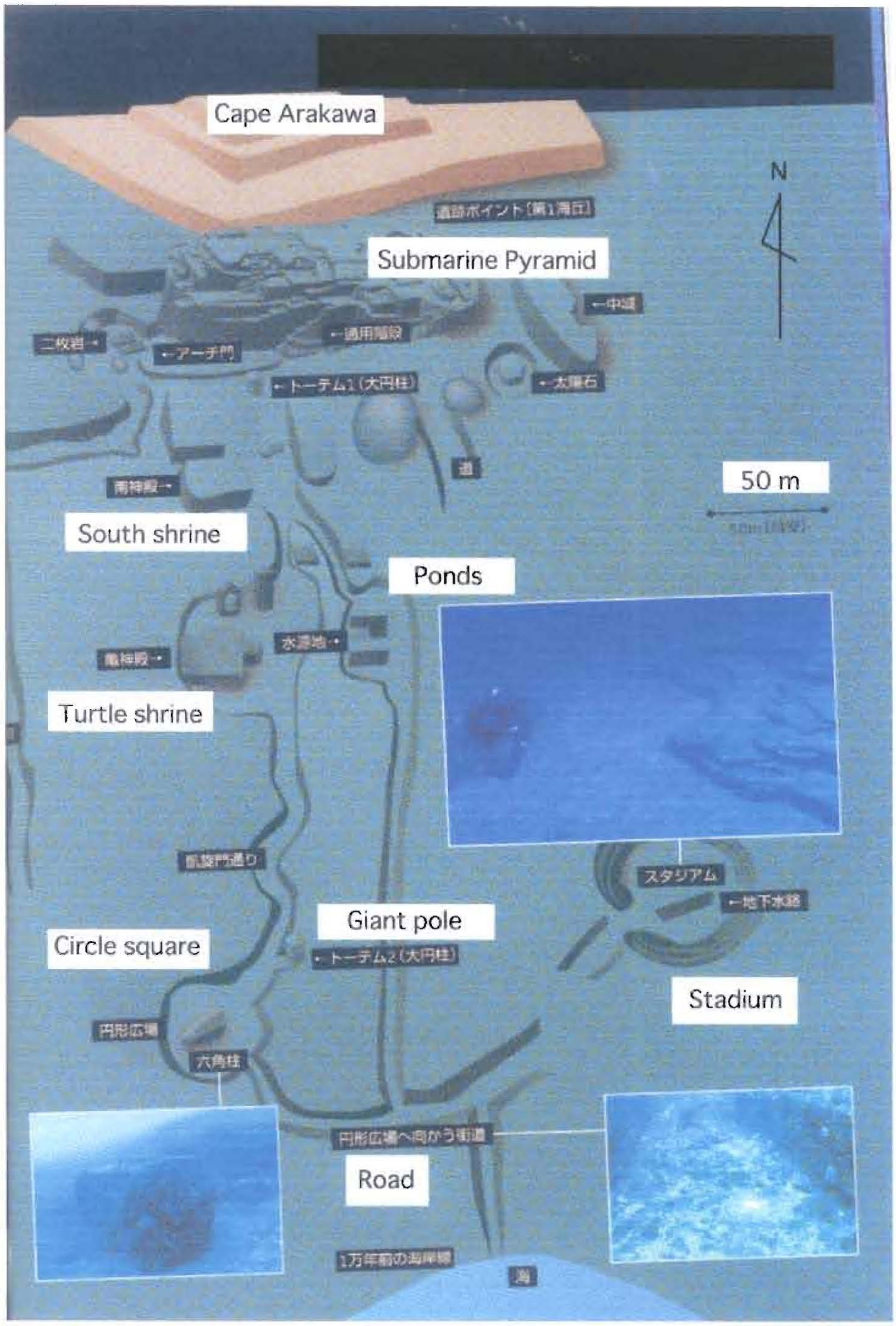


Figure 5: Iseki Point and its vicinity in the southern part off Yonaguni Island, Okinawa after Kimura (2002a). This scenery looks like a part of ancient city of Roma.

were recovered from Kuchimino-Se Bank at 122m deep in the Tunghai Continental Shelf, providing a 14C date (from gelatine collagen of bone) of 26,000 years old. The reliability of this value is high at present (Nakamura *et al.*, 1996). Here, Pleistocene strata expose at the surface of the sea floor, judging from the sparker profiling records.

Subsidence of the last Ryukyu land bridge started when seawater invaded it about 25,000 years ago, judging by the age of normal sediments covering the basement rocks of the Kerama Gap, dated ^{14}C to 19,780 ± 330 Yr bp.

Much of the above-mentioned evidence shows that islands were connected from the Chinese continent through Taiwan, Okinawa, and Amami Islands to Kyushu mainland by the land early stage since 0.2 Ma (Riss Glacial Age) (Table 1). And then, the bridge was interrupted by water at least 0.04 Ma, in Tokara and Kerama Gaps.

Recently, submarine stalactite caverns have been discovered off islands of Ryukyu Arc at about 20-40 m deep (Fig. 4) (Kimura and Nitta, 1996; Kimura, 2002a). Two pieces of stone tools were recognized inside one of the submarine caverns, Ginama submarine cavern (Kimura and Nitta., 1996, Kimura *et al.*, 1996). On the contrary, artificial constructions (Fig. 9) were found about 20 - 40 m below sea level, which estimated to be constructed around 10,000 years ago (Kimura *et al.*, 1999, Kimura, 1997, Kimura, 2000a, 2002a) (Fig,5). If these have been submerged since 10,000 years ago, then average speed of subsidence is almost coincident with the rate of eustatic movement since 10,000 years ago near the islands (Kimura, 2001a,b, 2002b).

THE MAJOR TECTONIC force for uplifting and subsiding movements since 0.2 Ma may have been generated by the sub ducting plate motion in the Nansei-Shoto (Ryukyu) Trench, rifting movement of the Okinawa Trough back-arc basin and eustatic movement.

Reconstruction of paleogeography

Reconstruction of paleogeography since the late Miocene was performed and reconstruction of rivers and water channels were attempted (Figs. 8 and 9).

7.0 - 5.0 Ma (First stage land connection)
THE RYUKYU ARC may have been fundamentally a southeastern part of the land of Eurasian continent (Fig. 10-1, -2). The relative sea level, however, was increased and the Shimajiri Group deposited in the sea during 5.0-2.0 Ma.

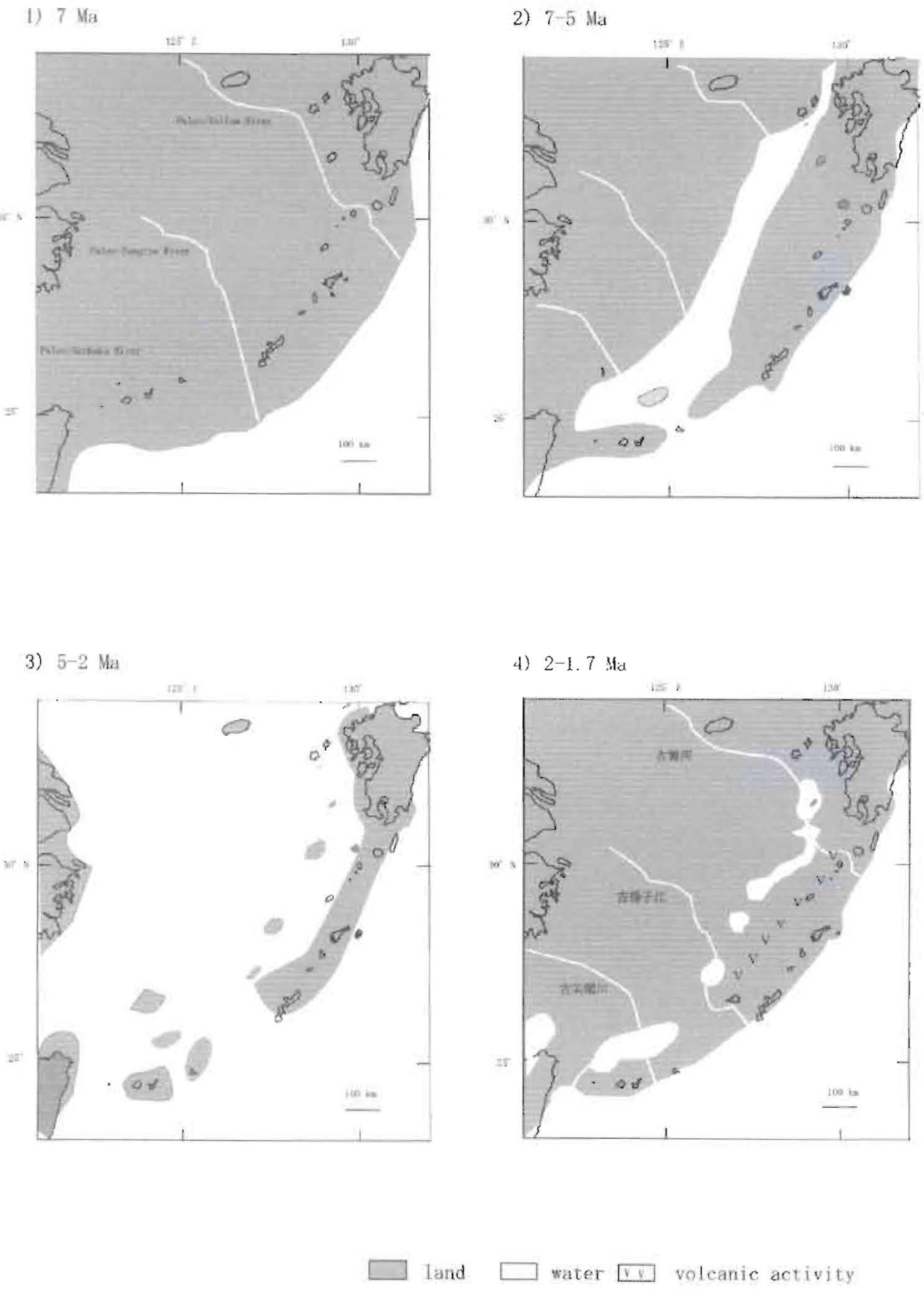
2.0 - 1.3 Ma (second stage land connection)
From the late Pliocene to in early Pleistocene times (2.0-1.7 Ma), most of East China Sea dried up yielding vast dry land (Fig. 4). A series of lakes appeared in the future-Okinawa Trough region. One big lake existed at Kuchinotsu in Kyushu. Layer B_1 may have deposited in those lakes. Later subsidence of the newer Okinawa Trough started along the series of lakes.

Rivers originating from the Asian continent (many from the Himalaya Mountains) would have trended from northwest to southeast, opening to the southeastern coast. Goto Submarine Canyon may have been a part of Paleo-Yellow River (Kimura *et al.*, 1975), and probably was continued to the pacific coast through the Tokara Gap. The Yangtze River may have opened at the Kerama Gap to the south of Okinawa Jima Island.

The unconformity below the Chinen Sandstone Formation in the south of Okinawa-jima shows a major tectonic event of this time.

1.3 - 1.0 Ma (Okinawa Trough Stage)
At this time water level rose relatively and the sea spread out. In Kerama Gap, the

Figures 6: Paleogeographic map of the East China Sea and the Ryukyu Arc region often Kimura (2002b) and Otsuka and Takahashi (2000).



Ma: Million years ago

Fig. 6-1

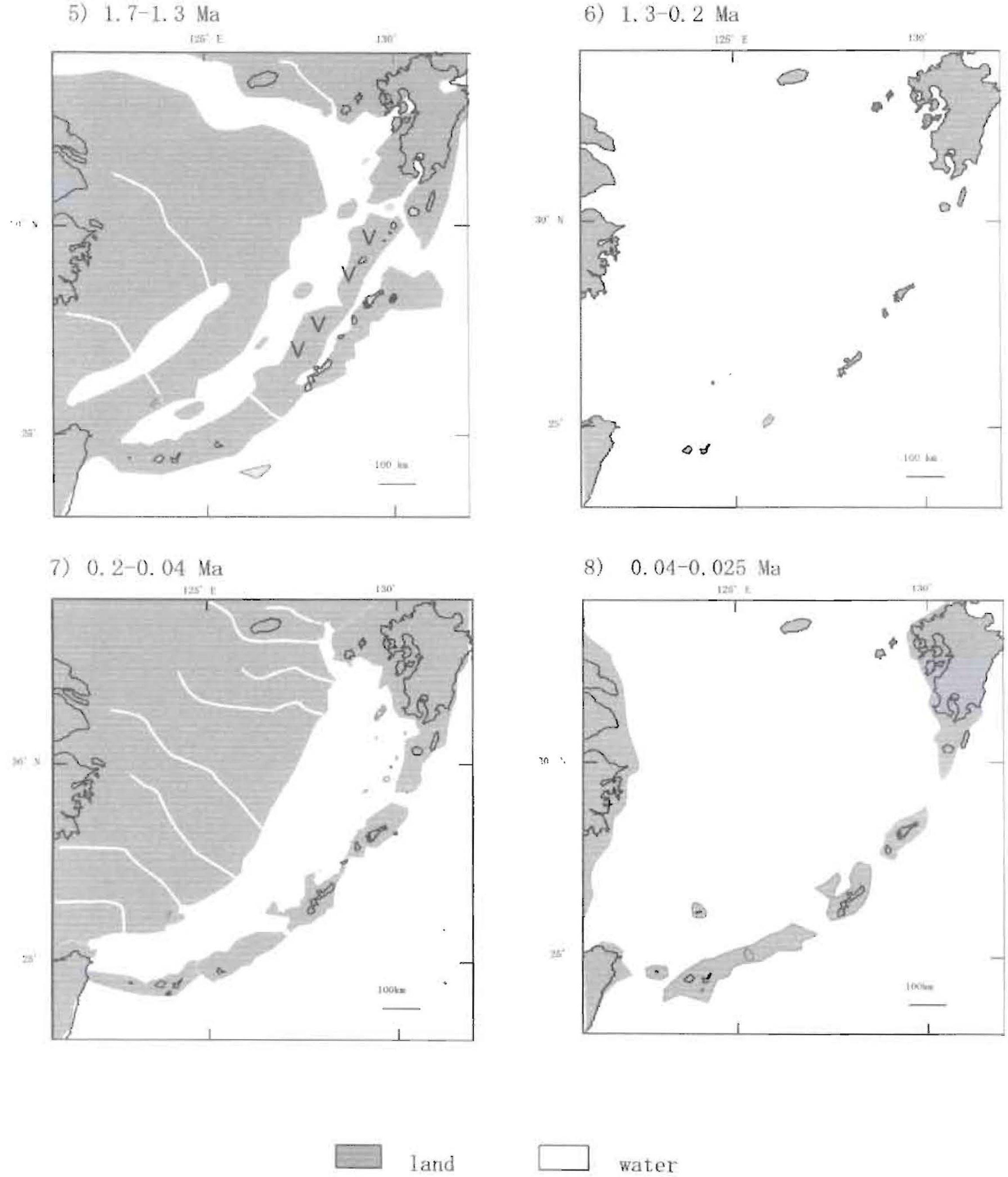


Fig. 6-2

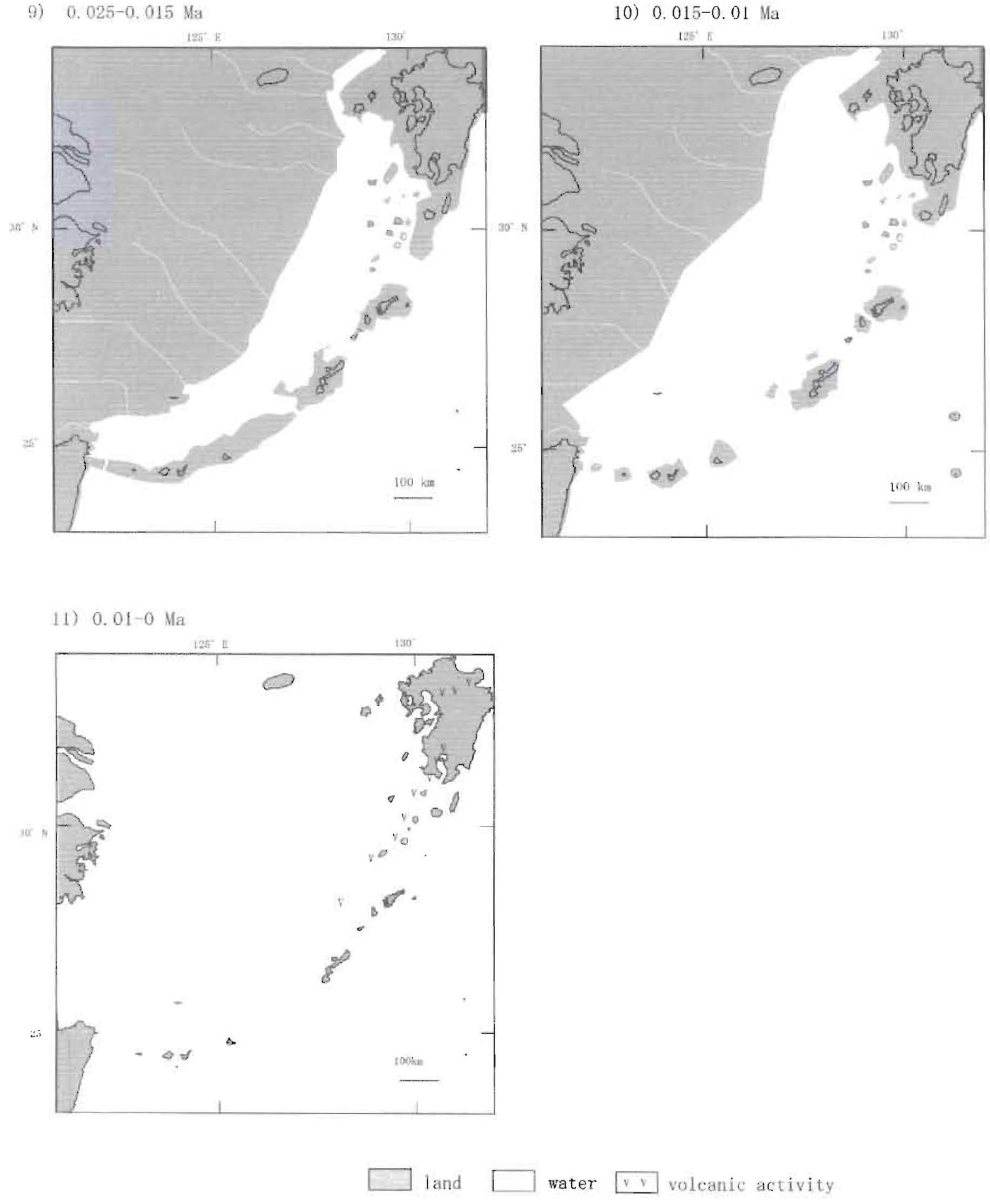

9) 0.025-0.015 Ma
10) 0.015-0.01 Ma
11) 0.01-0 Ma
100 km
land
water
volcanic activity

Fig. 6-3

Chinen Fm of the Shimajiri Group was eroded, which may have been emerged and under erosional conditions between 1.3-1.0 Ma (post-Chinen Formation). The Ryukyu Arc seems to be a land bridge connecting China to Amami-Oshima Island.

IT IS CLEAR that there is definite lack of strata during and after formation of the Shimanto Terrane and before that of the Ryukyu Limestone in the Tokara Gap. However, there are outcrops of younger sediment probably correlated with Kuchinotsu Group in Shimabara, Kyushu below Holocene sandy sediment. It is assumed that the Tokara Gap was inundated from 1.7 - 1.3 Ma, because marine deposits distributed in Shimabara which is western inner area to the gap. Seawater invaded Okinawa Trough at this time. Invasion of seawater toward the inside the Trough is recognized as marine sediment in the Kuchinotsu Group in central Kyushu (Okaguchi and Otsuka ,1980). The Kita-Arima Fm of the Kuchinotsu Group seems to coincide with that of actual transgression time. Seawater invaded the Inland Sea (Setonaikai Sea) followed by deposition of the Kita-Arima Formation (Okaguchi and Otsuka, 1980; Otsuka, 1998). Thus, the Tokara Gap would have been opened as represented in Fig. 8-2,-5.

1.0 - 0.2 Ma (Ryukyu Coral Sea Stage)

Subsequently, mud and sand from the continent have been trapped in the trough, followed by growth of corals in the clear sea along the Nansei-Shoto Islands. These corals formed the lowest part of Ryukyu Limestone (Reddish Limestone) in this stage.

Between 1.0 - 0.2 Ma sea level rose tremendously, during which sea area increased. Most land area had been submerged by water (Fig. 4-2,6)). Because the sea nearly covered the present Ryukyu Islands, land mammals could not reach Ryukyu and Honshu from the continent at this time. High points were still land areas and corals grew along the shallow water.

Coral reefs were formed broadly along the summit of the Ryukyu Ridge as a result of sea-level rising; hence the Ryukyu Limestone was formed. However, Ryukyu Limestone is never recognized in the depths of Kerama and Tokara Gaps, where older strata such as the Shimajiri Group (Kerama Gap) and the Shimanto Super Group (Tokara Gap) are exposed above the sea. Perhaps there were water channels and under water erosional environments, in which some coarse sediment deposited, preventing formation of Ryukyu Limestone parts of Kerama and Tokara Gaps. Günz-Mindel Interglacial period is represented in this stage. Nonetheless, formation of limestone was completed in the margins of the Okinawa Trough and peripheral seas.

At Nansei-Shoto archipelago, an unconformity exists between Pleistocene Naha Limestone and Yomitan Limestone, which possibly correlates with Mindel glacial epoch. Fossil crabs and oysters are found in a part of the Sonan Fm on a plateau of approximately 40 m above sea level in Sonan and Kisembaru in central Okinawa. Ages of 520,000 - 300,000 Yr Bp were measured using shell fragments by ESR technique (Kimura, 1997). This geologic sequence is identified as transgression sediment overlying above-mentioned unconformity. It might have been a land bridge from the contoinent to Okinawa Islands. However, evidence, is a sparse. Then, the coral grew up in the sea of those days and formed a Limestone in Mindel glacial epoch.

SEDIMENTS WERE deposited in the sea after the Mindel ice age when it is thought that the land bridge was cut off by the rising sea-levels.

0.2 – 0.015 Ma (Third Stage land connection)

In the Ryukyu island chain, a large upheaval occurred between 0.2 – 0.04 Ma (Fig. 4-2, -7). A land bridge appeared after approximately 0.2 Ma. Strata older than the Ryukyu Group were eroded and exposed, forming a land bridge. This land bridge was formed between the Riss glacial epoch and Würm glacial epoch.

NEARLY THE entire Ryukyu Ridge emerged, increasing land areas. Basement layers of the Ryukyu limestone crop out directly in the central part of the Kerama and Tokara Gaps (or Saddles). This suggests that the center of the Gaps may have uplifted and had eroded more than neighboring areas in the Ryukyu Ridge after deposition of the Ryukyu Limestone formations. As a result, a land connection from Chinese continent to Ryukyu Arc had been formed just since 0.2 Ma. After that, the Tokara Gap has been subsided and then the Kerama Gap has been subsided by normal faulting movement.

The Kerama calcareous layer (Kerama Limestone) was deposited 40.000 – 25.000 years ago. This suggests that at least a part of the land bridge may have been disconnected from the continent. The Kerama Limestone was eroded unconformably because of sea level lowering by the eustatic movement after then. The land bridge to the Ryukyu Arc may have appeared, allowed Minatogawa Man access to the Ryukyus.

Normal faulting since 30.000 Yr Bp, during which time the last land bridge began to be inundated, owing to crustal movement, has offset the flat plane of TA. Fig. 4-3, -9 shows a paleogeographic map between 15.000 – 25.000 Yr Bp. At this time, shallower part than about present 500 m deep may have land areas, because sediments of this age were recovered deeper than 500m. Then, relative subsidence has progressed by sea level rising since the ice age. The Kuroshio Current began to flow through west of the Nansei-Shoto archipelago, finally to result in the state.

Migration of human beings was identified after 32.000 years ago in Ryukyu Islands.

Architectural ruins recently found underwater off Ryukyu Islands were identified underwater at 35m depth in Yonaguni Island. This is estimated to have submerged since 10.000 years ago, showing coincident with post-glacial eustatic movement (Kimura, 2000b).

Conclusion

Paleogeographic maps showed three land connection stages from Eurasian continent to Japanese islands since late Miocene time. Major land connections between Eurasian continent and Ryukyu Islands have appeared at 7.0-5.0 Ma, 2.0-1.3 Ma and 0.2-0.015 Ma. Many ^{14}C ages achieved from fossil mammal bones suggest strongly the existence of the ultimate land bridge from the continent to Amami Islands may have existed until the Würm Ice Age. The last land bridge has been submerged since 0.015 Ma, according to sea level rising after the ice age and crustal movements, averaging 1 - 2 cm/yr.

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Correspondence address:

Prof. Dr. Masaaki Kimura
Department of Physics and Earth Sciences
University of the Ryukyus
Senbaru 1, Nishihara,
Okinawa 903-0213, Japan.

E-mail: kimura@sci.u-ryukyu.ac.jp
Caption

近年の潜水調査を含む海底の地質・地球物理学的研究成果をまとめることにより、ユーラシア大陸と日本列島とが、第四紀更新世後期に日本列島が陸でつながった時期があったことが明らかになった。琉球弧の形成過程では、中新世以降大きく分けて 3 回の大陸と陸繋期（陸続きになった時期）が区別された。I 期はおよそ 700 万年前、II 期は 200-130 万年前、III 期は 20 万-1.5 万年前である。第 1 期は、700-200 万年前である。700 万年前かそれ以前は、日本列島南西部に位置する南西諸島（琉球弧）は、ユーラシア大陸と一連の陸域であった。そこに水域が入り込んできて琉球古陸が形成された。この時期に一度大陸と完全に分断された琉球古陸が再度ユーラシア大陸の一部となる。東シナ海域は広範に陸化し、その時琉球弧はユーラシア大陸の一部となった。現在の沖縄トラフのかなりな部分が陸化した。第 III 期では、20 万 – 1.5 に、台湾を通って中国大陸と陸橋としてほぼ連続していたとみられる。琉球古陸はおよそ 3 万年前以降、地殻変動と後氷期の海面変動の両者によって段階的に沈水していった。琉球弧の水深 10 - 35 m の海底には鍾乳洞が次々と発見されている。それらの洞穴はウルム氷期以降に沈水したものである。そのうちの 1 つからは石器が得られた。さらに、10,000 年前頃に形成されたと推定される古代の城のような形をした人工的な構造物が、沖縄県与那国島沖の海底から発見された。そのような遺跡の存在は琉球弧の沈水過程を解明する手がかりを与えるものとなろう。