Geology of the island arcs in the northwestern margin of the Pacific Ocean and their formation by a large-scale uplift and sea level rise – the formation of Suruga Bay

Masahiro Shiba
Natural History Museum, Tokai University,
2389, Miho, Shimizu, Shizuoka, Shizuoka, 424-8620, Japan
shiba@dino.or.jp

Abstract: Suruga Bay, the deepest bay in Japan, has been formed by a large-scale uplift by thrust faulting and absolute rise of the sea level by about 1,000 m since 400 Ka ago. In order to form a stratum, it is necessary to uplift the crust and elevate the absolute sea level, which means the Micro-Expanding Earth. In the Jurassic period, the sea level was 5,000 to 6,000 m lower than the present. After that the strata and the topography were formed due to uplift of the crust and rising sea level by the eruption of the flooded basalt on the ocean floor. From the Cretaceous, the plutonic igneous activity and the uplift of the continental margin of the Pacific Rim began. In the late Miocene, the arc began to form by uplift of the crust. A combination of large-scale uplift and sea level rise by about 1,000 m since 400 Ka ago ultimately formed the topography as seen today.

Keywords*: large-scale uplift of the crust, sea level rise, expanding Earth, Japanese Islands, formation of the present topography.*

(Received 28 October 2017. Accepted 11 November 2017)

Introduction

I recently published a book "Formation of Suruga Bay – Large-scale uplift of arc and sea level rise" (Shiba, 2017). This book is the compilation of my geological research, and the present article corresponds to the English summary of the book.

Suruga Bay is located in the center of the Japanese Island arc in the northwestern margin of the Pacific Ocean (**Fig. 1)**. Suruga Bay is the deepest bay in Japan, its maximum depth is about 2,500 m at the bay entrance, and it has a depth of 1,500 m even in the east off the Miho Peninsula in Shizuoka City, central Japan. In Suruga Bay, a deep, narrow grooved canyon is extending linearly in the north-south direction at the center of Suruga Bay (**Fig. 2**). This canyon is currently called the Suruga Trough but the topography of this canyon is not a trough, then I call it the Suruga Bay Central Channel (Hoshino et al., 1982) in this paper.

Suruga Bay is located in the western margin of "Fossa Magna" which traverses the center of the Honshu Island. The Izu Peninsula is located in the east, Mt. Fuji in the north, and the Akaishi Mountains (Southern Alps of Japan) which is the largest uplift area in Japan in the northwest. The position of Suruga Bay is currently said to be the boundary between the so-called the Philippine Sea Plate and the Eurasian Plate; therefore it is the first research topic of geology to clarify how Suruga Bay was formed.

The question, "How Suruga Bay and its surrounding mountainous ranges were formed?", is not only related to the formation of Suruga Bay, but also to the entire island arcs in the northwestern margin of the Pacific Ocean, or the Japanese Islands. Its elucidation gives hint how the continent and the ocean floor of the entire Earth were formed.

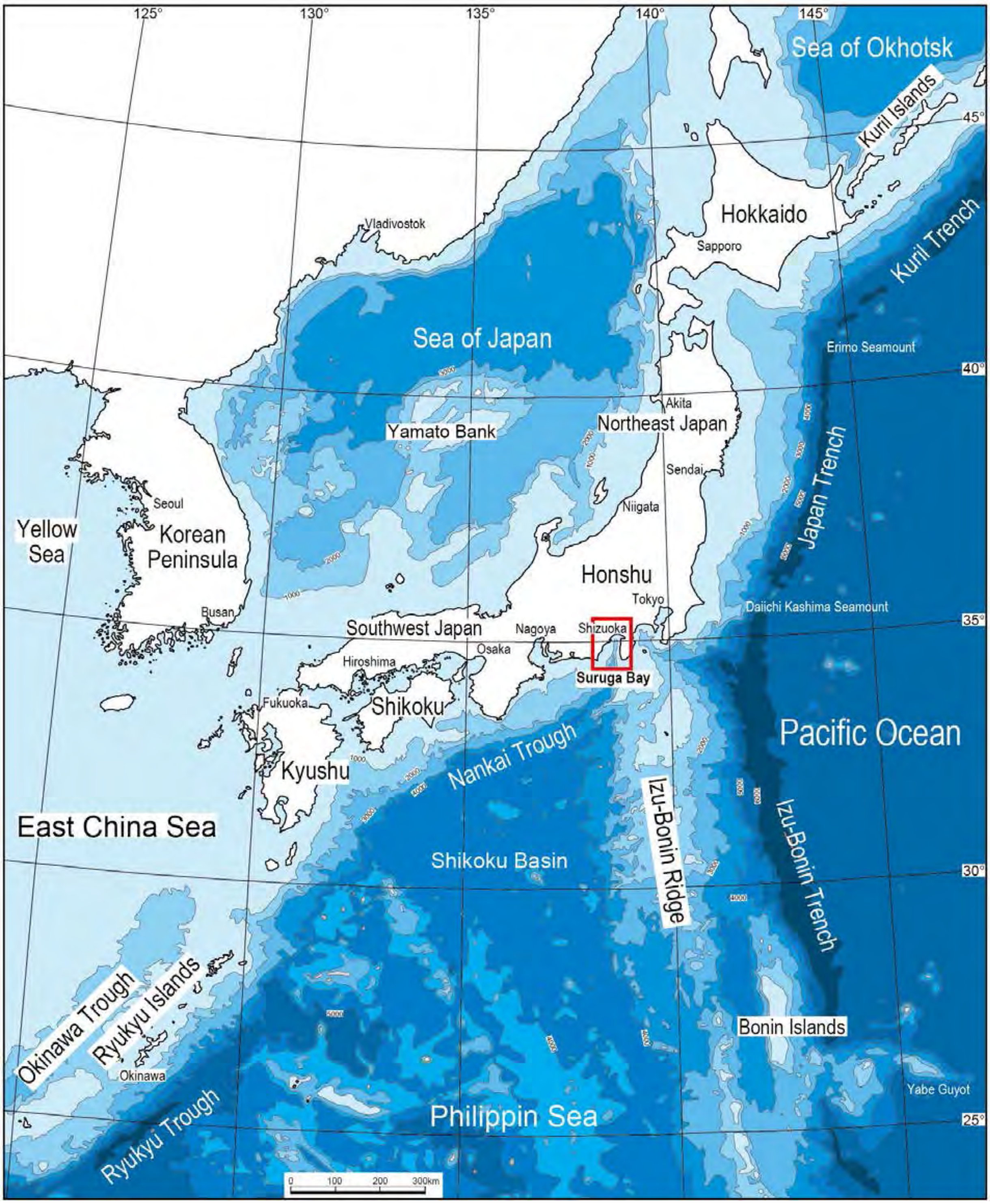

Fig. 1. Submarine topographic map of the northwestern margin of the Pacific Ocean showing the location of Suruga Bay. The red frame shows the area of Fig. 2.

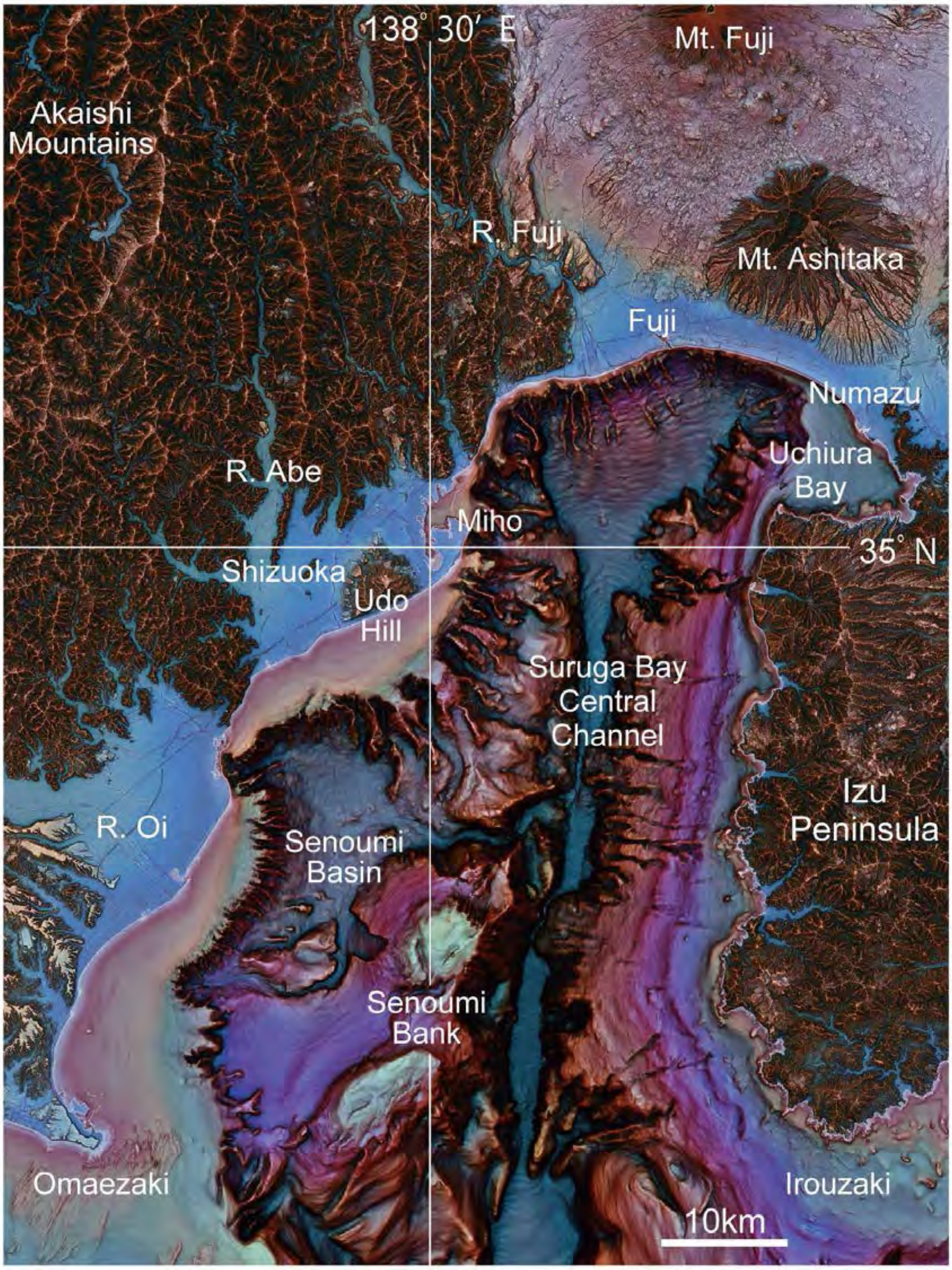

Fig. 2. Detail geomorphic map of Suruga Bay and the surrounding area. This area is shown in the red frame in Fig. 1. Offered from Asia Air Survey Co. Ltd., Tokyo.

Formation of Suruga Bay

The seafloor on the side of the Izu Peninsula of Suruga Bay **(Fig. 2)** consists of nearly uniform continental slope inclined towards the Suruga Bay Central Channel, except the Uchiura Bay. There is the Senoumi Bank on the western side of the Suruga Bay Central Channel, and is the Senoumi Basin of about 900 m deep between the Senoumi Bank and the continental slope of the west coast of Suruga Bay. The Fuji, Abe and Oi Rivers flow from the Akaishi Mountains, draining into the center to the west coast of Suruga Bay.

The Udo Hill which is located at the southern area of the Shizuoka Plain, is a fan-delta formed in the last 300 Ka. This fan-delta was formed at the mouth of the Abe River, which was formed by a large uplift and six times of sea level rise (**Fig. 3**). Since the fan-delta of the Udo Hill was formed by a large-scale uplift, it is considered that the amount of fall of the sea level represents the amount of the uplift, without absolute fall of the sea level. Therefore, the accumulated absolute rise of sea level during that time was about 900 m (Shiba, 2016a).

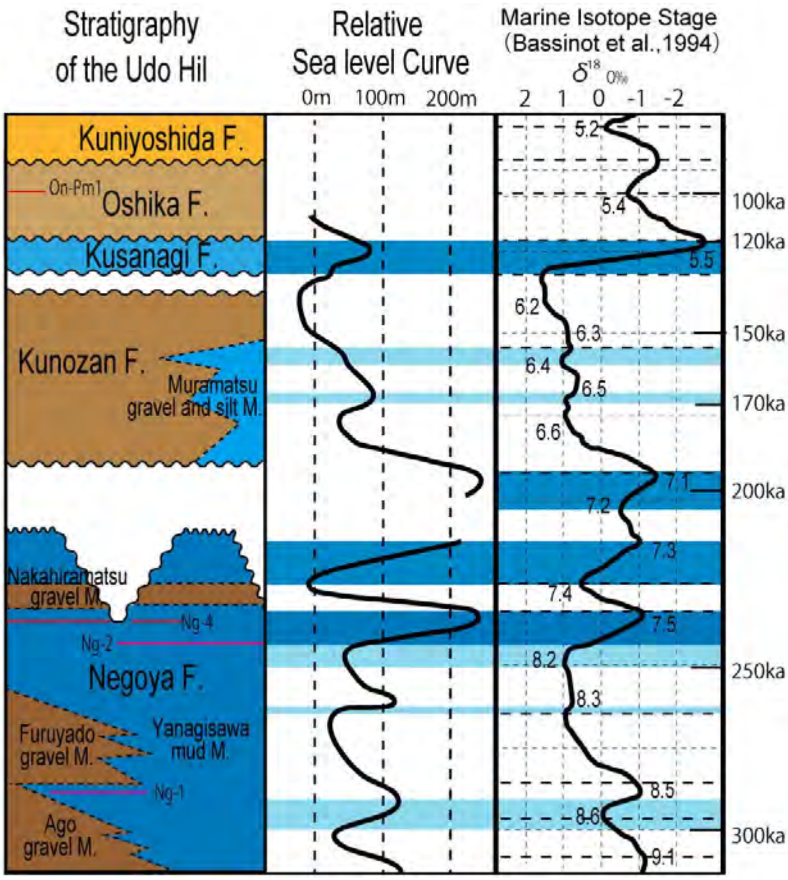

Fig. 3. Relative sea level curve estimated by the sedimentary process of the stratigraphy of the Udo Hill and the oxygen isotope curve by Bassinot et al. (1994). The stratigraphic map shows some modifications of Shiba et al. (2012). Ng-1 and so on is volcanic ash layers. Numbers of the marine oxygen isotope curves are numbers of marine oxygen isotope stages (MIS). Ka: thousand years, F.: Formation, and M.: Member.

The gravel bed of the fan-delta of the Abe River is also distributed on the top of the Senoumi Bank in Suruga Bay (Lower Yaizu-oki Group in **Fig. 4-A**), and the gravel bed on the top of the Senoumi Bank deposited about 400 Ka ago. From this, it is thought that the Senoumi Basin was subjected to relative subsidence of about 900 m to the sea level in the last about 400 Ka. On the other hand, an erosional unconformity plain is founded on the continental slope (1,650 m in depth) of the Izu Peninsula, which was on land between the Late Pliocene and the Early Pleistocene (Truncated Surface in **Fig. 4-B**). It is thought that both sides of the continental slope of Suruga Bay relatively subsided about 1,000 m in the last about 400 Ka.

From these facts, it is thought that the Senoumi Bank and the both sides of the coasts of Suruga Bay uplifted in the last 400 Ka, with simultaneous gradual sea level rise by about 1,000 m. As a result, the Senoumi Basin submerged and the Senoumi Bank isolated. In other words, Suruga Bay was formed by a large-scale uplift movement of the arc occurred since 400 Ka ago with the absolute sea level rise of about 1,000 m. This movement is called the “Udo Movement” (Shiba, 2016a).

The edifice of the Senoumi Bank also consists of the fan-delta sediments supplied from the Abe River since 1.8 Ma to 400 Ka ago, which is called the Senoumi Group (**Fig. 4-A**). In this age when the Senoumi Group was deposited on the Senoumi Bank, the Ihara Group was formed a fan-delta at the estuary of the Fuji River and the Ogasa Group was formed a fan-delta at the mouth of the Oi River. Also in this age, the Akaishi Mountains uplifted on a large-scale, the continental slope of the island arc was buried and the land expanded to offshore. Near the end of this age, Japanese Islands were related to the Chinese and Korean mainland; the present biota of the Japanese Islands was emigrated during this time. This age of the large-scale uplift is called the "Ogasa Movement" (Shiba, 2016a).

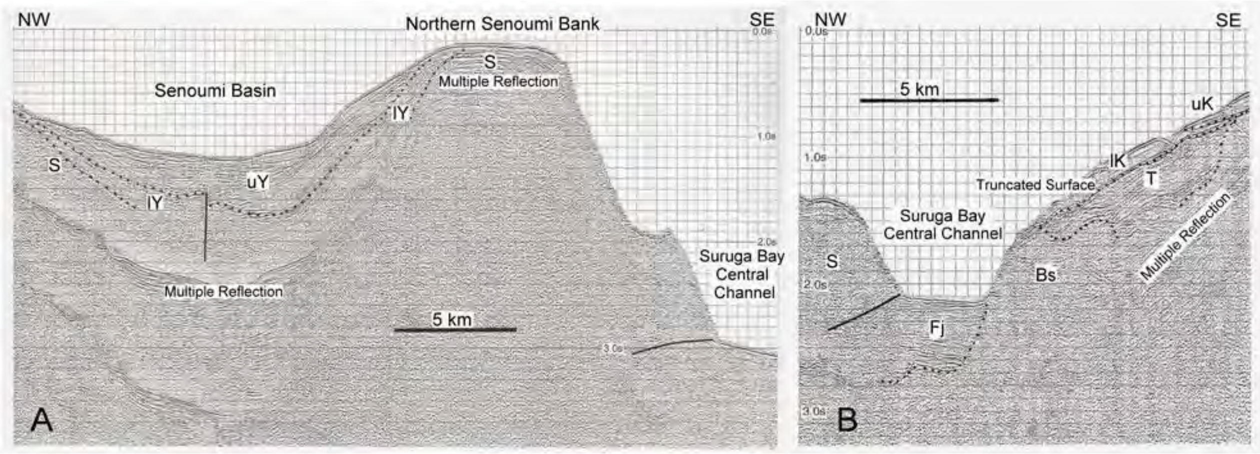

Fig. 4. Seismic sections in Suruga Bay from Northeast to Southwest (Okamura et al., 1999). A: western side of Suruga Bay, B: eastern side of Suruga Bay, or continental slop of the Izu Peninsula, Bs: Basement, T: Toi Group, S: Senoumi Group, lY: Lower Yaizu-oki Group, uY: Upper Yaizu-oki Group, lK: Lower Kamo-oki Group, uK: Upper Kamo-oki Group, Fj: Fujikawa-oki Group.

In the latest Miocene epoch about 6 Ma ago, the sea level was 2,000 m lower than the present (Hoshino, 1962) and the northern part of Suruga Bay was land (**Fig. 5-a**). In the Pliocene epoch about 5 Ma ago, the land masses in the Izu Peninsula and the western area of Suruga Bay rose, while also the sea level rose. In the Izu Peninsula the Shirahama Group deposited in the shallow water envelopment, and in the northwestern area of Suruga Bay the Hamaishidake Group deposited in the narrow long trough of the N-S trend (**Fig. 5-b**). Between the Late Pliocene and the Early Pleistocene, the western coast of Suruga Bay and the Izu Peninsula were uplifted, and the land expanded on both sides of Suruga Bay.

About 1.8 Ma ago the sea invaded the northern part of the Izu Peninsula, but most of the Izu Peninsula and its continental slope were land. At that time, the western side of Suruga Bay was under water, and a fan-delta formed by the sand and gravel carried by the Abe River from largely uplifted Akaishi Mountains; it buried widely the seafloor of the western side of Suruga Bay about 400 Ka ago (**Fig. 5-c**). These sediments which filled up the seafloor correspond to the Senoumi Group. At the same time, the fan-delta of the Ihara Group was formed in the inner part of Suruga Bay.

Then, between 400 Ka and 300 Ka ago, a gravel bed of fan-delta of the Abe River reached the summit of the Senoumi Bank (**Fig. 5-d**). The Senoumi Basin was submerged from east to west step by step due to the uplifting of the land accompanied by the sea level rise. Subsequently the Senoumi Bank was isolated. Approximately 300 Ka ago, a fan-delta of the Abe River deposited gravel and mud beds in the present Udo Hill. After the deposition, the south side of the Udo Hill further rose and the north-side sloping hill was formed. The Senoumi Basin and the Suruga Bay Central Channel became a deep seafloor by the sea level rise together with the uplift on both sides of Suruga Bay and the Senoumi Bank (**Fig. 5-e**).

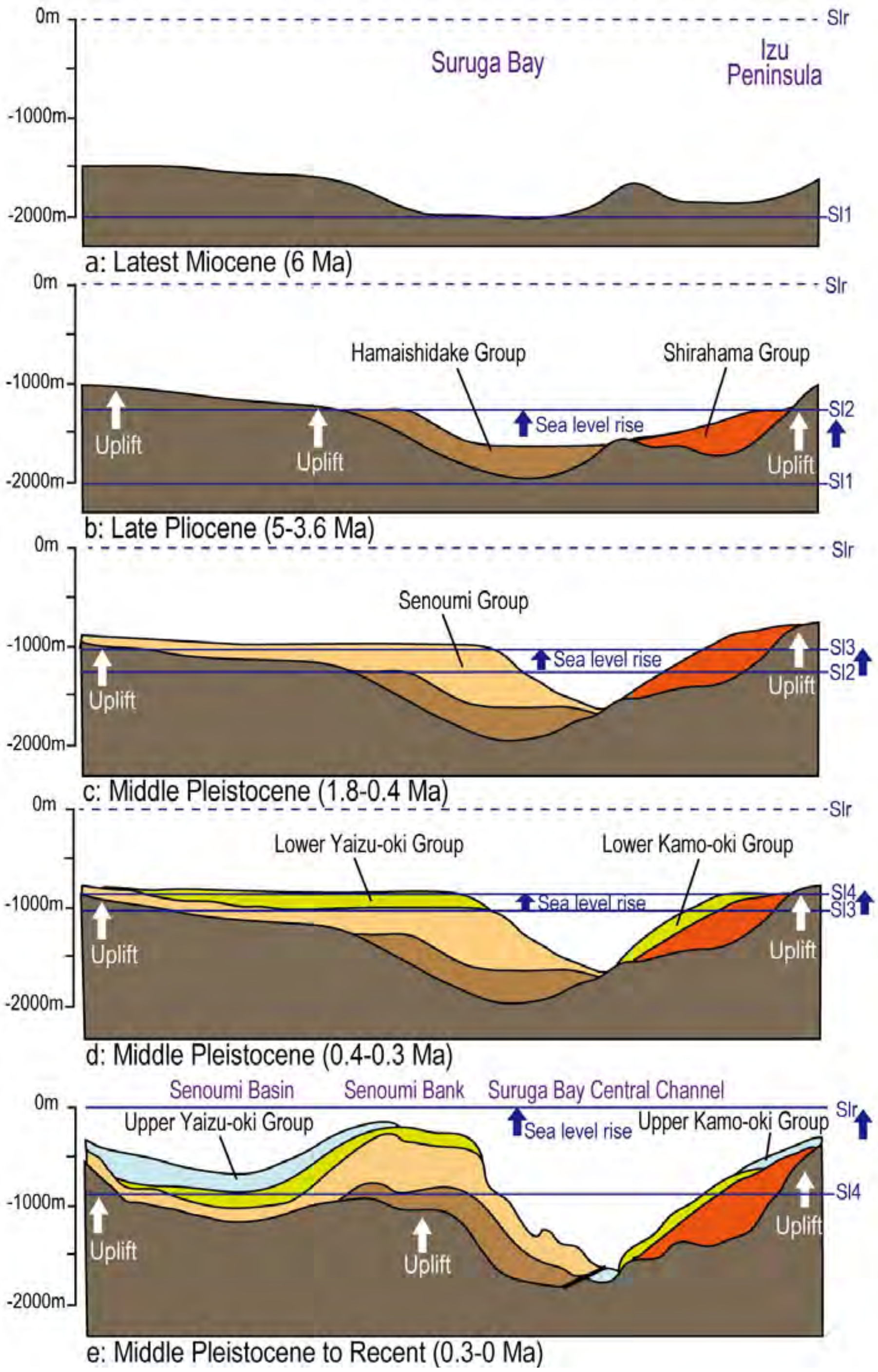

Fig. 5. Model showing formation of Suruga Bay by geographical section of E-W direction in each stage. Sl is the sea level and Slr is the present sea level (Shiba, 2017).

Formation of strata and sea level rise

We can know the record of geological time from a stratum that was formed in the past, but how can a stratum be formed and preserved until today, and why can we see a stratum deposited on the seafloor even on land?

If it is a terrigenous stratum, it is necessary for forming stratum to supply clastic sediments such as mud, sand and gravel (1). It is also necessary to prepare sedimentary space to be deposited (2), and to a setting to store and accumulate the strata (3).

For supplying the clastic materials (1), relative uplift of the hinterland (or the relative fall of the sea level) is necessary. In addition, the preparation of the sedimentary space (2), and accumulation of the strata (3), and the relative subsidence of the crust (or the relative rise of sea level), are necessary. In other words, either the relative uplift and the subsidence of crust, or the relative fall and rise of the sea level must occur simultaneously for forming a stratum.

Traditionally, geologists have explained it with a simple model, in which the land uplifted and the seafloor subsided. However, because the sea level fluctuate up and down, the junction between the land and the sea level can't always be the boundary of the up and down movement of the crust. In addition, the strata deposited on the seafloor are distributed on land too; this seems to suggest that the crust of the seafloor also rises. That is, the simple model that the land uplifted and the seafloor subsided will not be established. Likewise, it seems contradictory that the sea level falls on the land and rises on the seafloor.

Therefore, to form a stratum, the crust must either uplift while sea level rises, or subside while sea level falls. As the seawater volume is constant, if the crust including the ocean floor rises and the sea level rises, the Earth will expand somewhat. Conversely, if both the crust and the ocean floor subside and the sea level falls, the Earth will contract (**Fig. 6**). I believe that the crust uplifts and the sea level rises, and that the Earth expands like the Micro-Expanding Earth (Hoshino, 2014).

Clasts supply	: Relative	Uplift	or	Fall of sea level
Sedimentary space	: Relative	Subsidence	or	Rise of sea level
Accumlation	: Relative	Subsidence	or	Rise of sea level

Above three elements must occur at the same time for a stratum to form.

Crust		Sea level		The Earth
Uplift	—	Rise	→	Expansion
Subsidence	—	Fall	→	Contraction

Fig. 6. Relationship between uplift and subsidence of crust and change of sea level to form strata (Shiba, 2016b).

Haq et al. (1987) proposed an attempt to generalize how the formation was formed. Based on the petroleum exploration records on the continental shelf and continental slope around the world, they investigated overlapping and distribution of the seafloor formation, and they made it clear that the unit of successive depositing of a certain formation is composed of three consecutive characteristic deposits as the Tracts.

One unit of the formation deposited was called "Sequence", exactly "Third Order Sedimentary Sequence" (**Fig. 7**). And it is explained that a sequence was formed by a sea level fluctuation and crustal subsidence. Then, they estimated the amount of change in the sea level of each third order sequence and proposed a sea level fluctuation curve based on it after the Mesozoic era (Haq et al., 1987). The stratum formation model of this sequence has a prerequisite that the crust will sink at almost at the same speed. If the crust does not settle down below sea level, a stratum formed by sea level fluctuation will be eroded, so this model is based on the subsidence of the crust. Although this model has a problem in this respect, it is very important in explaining the formation of a stratum in a definite form with the mechanism of sea level change.

The mystery as to why a stratum is present is not only formation of a stratum by this sequence set but also units of a stratum formed by one sea level change (the third order sedimentary sequence set) was preserved and a new sequence overlapping one after another was deposited. Even if a stratum is formed by a single sea level change, if the crust does not subside relative to the sea level, the formed stratum is removed by erosion.

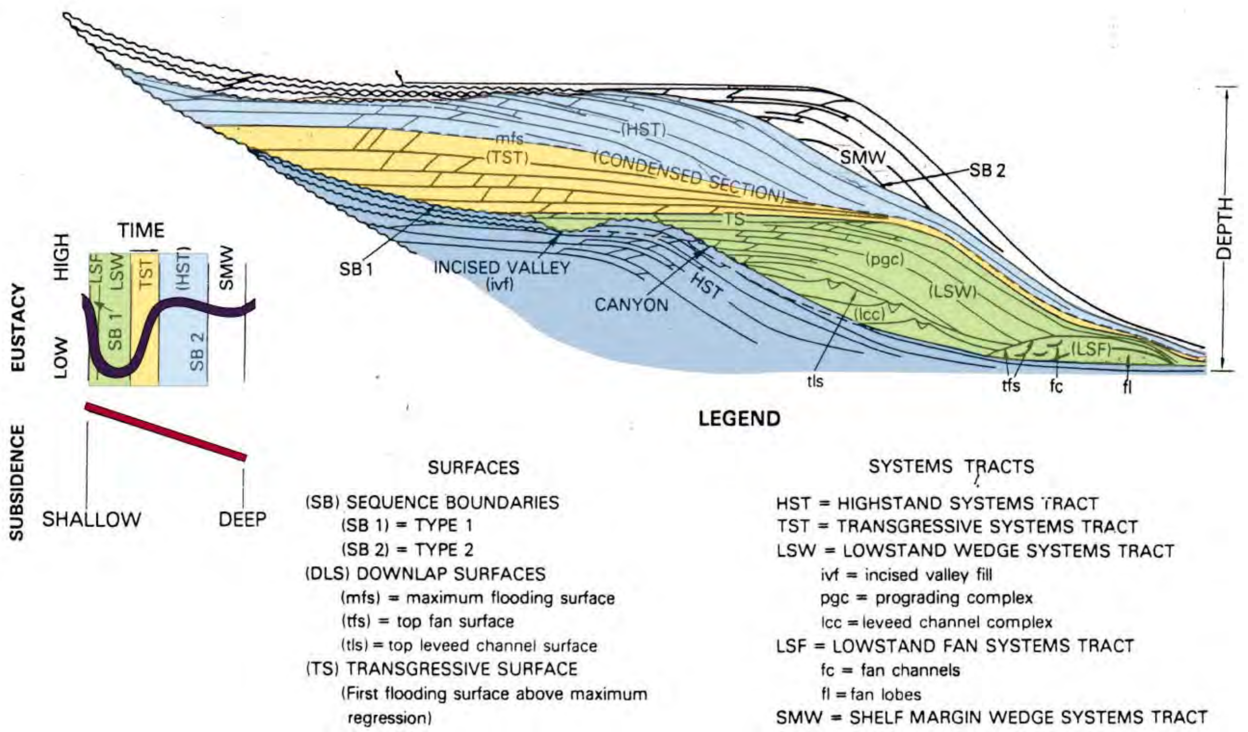

Fig. 7. Third order sedimentary sequence model by Haq et al. (1987).

Haq et al. (1987) said that the relative subsidence that preserves the strata was the subsidence of the crust due to sinking of the plate. However, I believe that the relative subsidence which preserved a stratum does not imply sinking of the crust, but the submergence due to sea level rise. I believe that what Haq et al. (1987) made as the sea level fall is the uplift of the crust. The characteristic features of the sea level change curves of Haq et al. (1987) and Vail et al. (1977) are that the sea level fall curve at the sequence boundary is a straight line rather than a curve. I think that this is to indicate a sharp uplift of the crust.

I made a sea level rise curve and a uplifting curve (**Fig. 8**) (Shiba, 1992) using the sea level change curve of Vail et al. (1977) which was the basis of the study of Haq et al. (1987). My sea level rise curve was made based on the accumulated the sea level rise of the Vail curve. Also, my uplifting curve is made of accumulated sea level fall of the Vail curve as the uplift. According to **Fig. 8**, the sea level rise since the Jurassic period is about 5.6 km, which is about 1,500 m after the Pliocene. Even if I did the same thing with the Haq curve, the amount of sea level rise was the same (**Fig. 8**).

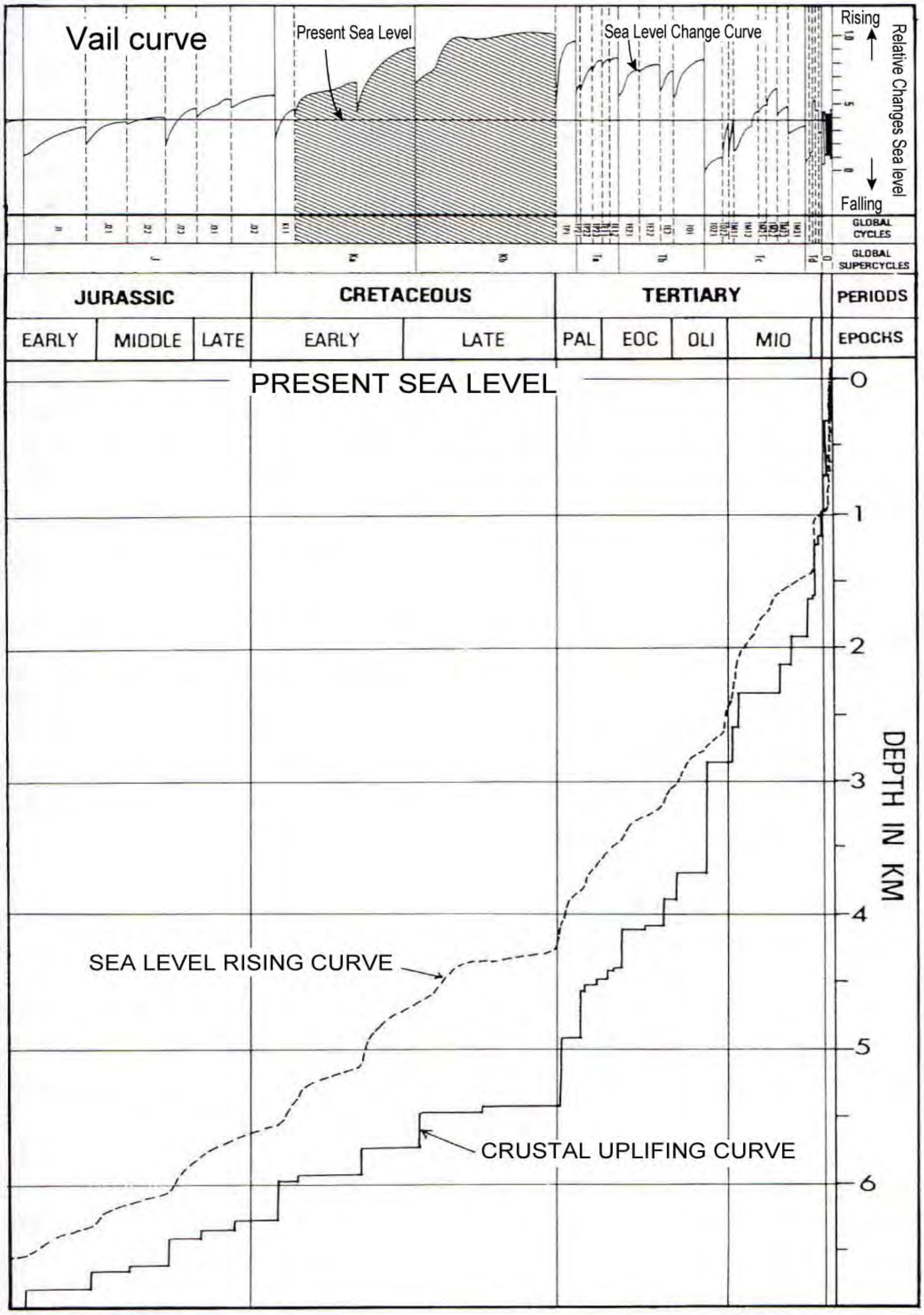

Fig. 8. Sea level rise curve and crustal uplift curve using the Vail curve (Shiba, 1992). Top diagram is the Vail curve that is the sea level change curve of Vail et al. (1977). The Vail curve can be separated into a sea level rising curve and a sea level fall curve. The sea level fall curve can be replaced by the crustal uplifting curve (polygonal line) which is made by accumulating the amount of fall and converting it to the amount of rise, whereas the sea level rise curve is made by accumulating the amount of the sea level rise only. Since the latest Miocene, the amount of uplift has increased, and the uplifting curve is above the sea level rise curve.

The characteristic feature of **Fig. 8** is that the sea level rise abruptly increased after the Pliocene and the uplift amount is further increased beyond that after the latest Miocene. This uplift is the amount of uplift in that area, as the study of Vail et al. (1977) covered the strata of the margin of the continent and the arc. Of course, the amount of uplift in the present terrestrial area seems to have been greater, so we can see the strata deposited in the past at the bottom of the sea recently.

Many sedimentologists studying the sedimentary sequence are seeking the cause of climate change like the glacial and interglacial periods to change the sea level rise and fall. However, from the estimates of the past climate around the world so far, it is doubtful that the possibility that a continental ice sheet of the same scale as that of the late Pleistocene has developed in the geological era after the Mesozoic before the early Pleistocene. Especially before the Pliocene about 2.5 Ma, we can't think of the glacial period accompanied by large-scale change of sea level. Therefore, the sea level change that formed the third order sequence before the Pliocene epoch can't be attributed to the expansion and contraction of the ice sheet due to climate change.

So, how did the rise of the sea level occur? Since the Mesozoic era, many parts of the crust which constitutes the surface of the Earth have risen. Elevation occurred not only in the continents and the island arcs but also in the ocean ridges and the ocean floor. What caused the uplift is the activity of basaltic magmas derived from the upper part of the asthenosphere. It seems that the magma rose through the upper mantle, and magma injected into the crust above the Moho discontinuity surface or erupted as lava on the ocean floor. The thickness of the oceanic crust of the ocean floor is about 5 km, and the sea level rise after the Jurassic is considered to be about 5 km (Hoshino, 1991).

I think that the sea level in the middle Cretaceous period (about 100 Ma) was about 4,000 m below the present sea level, in the Early Eocene (about 50 Ma) about 2,500 to 3,000 m below, in the latest Miocene (about 6 Ma) about 2,000 m lower, and in the Middle Pleistocene (to 400 ka ago) about 1,000 m lower than the present sea level (**Fig. 9**).

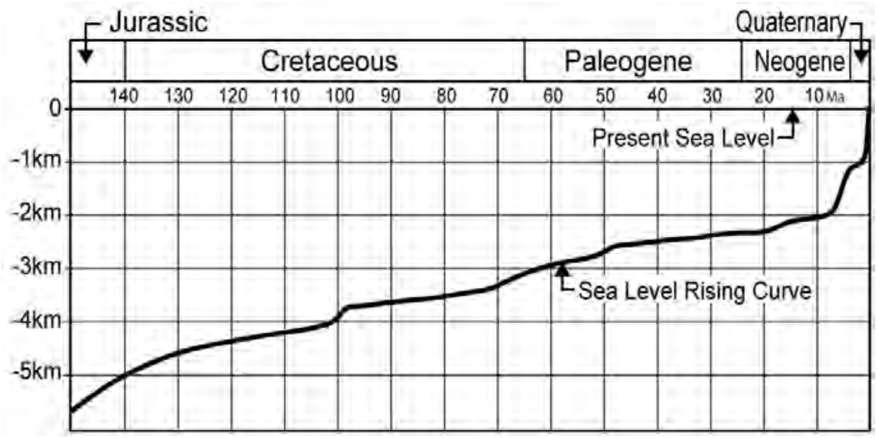

Fig. 9. Sea level rise curve after the Jurassic (prepared with reference to Hoshino, 1981).

The position of the sea level in the middle Cretaceous is the present summit depth of the Daiichi-Kashima Seamount (Shiba, 1993), in the Japanese Trench. The position of the sea level in the Early Eocene is the depth of the old land (Yezo Sedimentary Basin) on the Pacific side of continental slope of the Northeast Japanese arc (Ando, 2005), the depths of the Cocos Ridge and the Mozambique Strait. In addition, the position of the sea level of the latest Miocene corresponds to the depth of evaporates distributed in the Mediterranean basin (Hsü et al., 1977). The position of the sea level at about 400 Ka ago in the middle Pleistocene corresponds to the depth of the Senoumi Basin in the Suruga Bay. The deep ocean floor of the Gulf of Mexico has a depth of 3,600 m, and there is a thick salt layer of the Late Jurassic period (Uchupi, 1975) about 5,000 m below the present sea level. From these, the sea level in the Late Jurassic seems to be about 5,000 m lower than the present sea level.

After the Jurassic, the sea level rose due to the seafloor rising effect, which formed the present topography. The trench has been left from the uplift of the continental slope and the ocean floor. Guyots on the ocean floor are shallower than that those in the trench because the ocean floor was uplifted (**Fig. 10**).

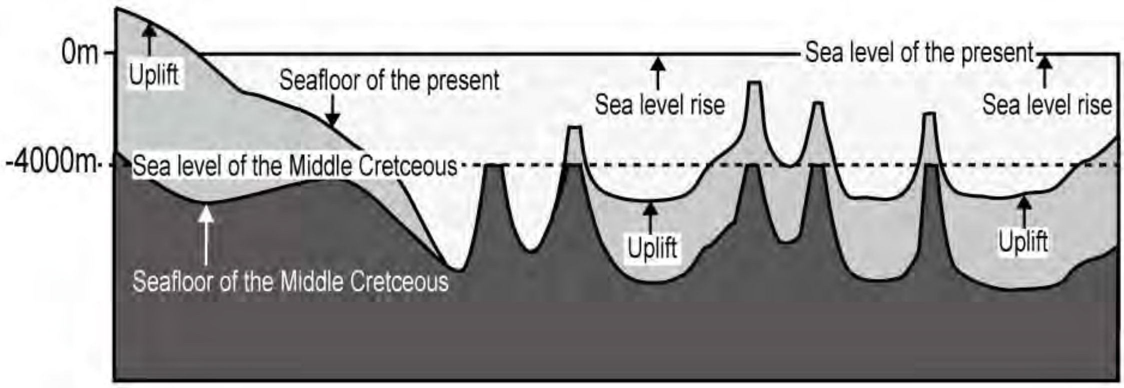

Fig. 10. Modelled topographical section of the middle Cretaceous and the present from the Japan Trench to the Pacific Ocean floor (Shiba, 1988). The uplift of the arc and the ocean floor has raised the sea level since the Late Cretaceous, and as a result the coral reefs in the middle Cretaceous become sunken islands as guyots which have the tops of various depths.

The arc-trench system formation

As a feature of the arc, the ocean side of the arc is framed by the trench, and on the back side of the arc, there is a marginal sea or a back-arc basin. For example, in the Japanese Islands the marginal sea is the Sea of Japan. There is also an earthquake zone (Wadachi - Benioff plane) diagonally from near the trench to the bottom of the crust, and many shallow earthquakes occur in the crust of the arc with active volcanic chains.

The area from the central part to the western part of Suruga Bay corresponds to the extension to the northern side of the Nankai Trough. This trough or trench corresponds to the Suruga Bay Central Channel, the outer ridge of this trench to the Senoumi Bank, and the fore-arc basin to the Senoumi Basin. The further extension of the Nankai Trough to the north will be the land on the north side of Suruga Bay. The Senoumi Bank and the Udo Hill have anticlinorium structures in the north-south direction, the Udo Hill is a land extension of the outer ridge, and the Shizuoka Plain which is inside of the Udo Hill corresponds to the fore-arc basin.

When the Ogasa Group and the Senoumi Group were deposited, between 1.8 Ma and 400 Ka ago, the crust uplifted on a large-scale, and mountains and mountain ranges were formed on land. Then a large amount of gravel eroded mountain ranges by rivers flowed down to form an alluvial fan, and buried the continental slope and spread land. The mouth of river, the estuary and the coast at this time reached the front of the present continental slope. In such a place a large amount of sand and mud accumulated near the trench.

After that, a large-scale uplift of the crust occurred roughly in the last 400 Ka. At the same time the sea level rose, the sea side of land submerged and in the area from the coast to the trench a steeply inclined continental slope was formed.

Inouchi et al. (1978) already stated that the present upper continental slope was formed after the middle Pleistocene. This is because that the uppermost formation accumulated on the continental slope since the middle Pleistocene deposited horizontally in harmony with the present topography, but the formation below it is distributed discordantly.

The formation of the mid-ocean ridge where the plates are allegedly born, the island arc and the trench as described by the plate tectonics, can be explained by the cyclical occurrence of similar movements all over the Earth. However, the continental slope has begun to form the present topography since about 400 Ka ago in the middle Pleistocene. The new crustal deformation shows a different movement from that before 400 Ka.

Vasiliev (1991) concludes that all trenches are new and formed in the Pleistocene. The present mountain ranges and the terrestrial topography, including submarine topography such as the continental slopes and trenches, and the present volcanic activities, had not existed or not been much active before 400 Ka.

Ultimately since 400 Ka ago they have formed or became active. This is related to a series of uplifting movements of the crust, such as the arc and the plateau started from the Miocene (about 23 Ma ago), especially a large-scale crustal uplift occurred at the late Miocene (about 11 Ma ago), and the newest structural movements of the crust (Udo Movement) which occurred after the uplift movement (Ogasa Movement) in the Early to Middle Pleistocene (1.8 Ma to 400 Ka).

The continental slope of the trench is supposed to be made up of the accretionary bodies from the ocean floor according to plate tectonics. However, most of the strata composing the deformed deposits along the Nankai Trough so-called accretionary wedges are sediments carried from the present land, and they are uplifted such as the late Miocene and the Pleistocene. The main deformation of the accretionary wedge is not always formed in accordance with the plate sinking into the trench, but the deformation is formed when each stratum is deposited or immediately after it. In other words, the deformed strata along the trenches, currently called “accretionary wedge”, were not formed by the movement of the ocean floor plate that always submerged into the trench, but were formed in certain specific ages of the uplift of the arc.

In addition, the land side area in the inner part of Suruga Bay is the land extension on the north side of the Nankai Trough. We actually observed and studied the upper Miocene to the Pliocene series in the Fuji River Valley, the Fujikawa Group and the Hamaishidake Group, which are considered to be inside the accretionary wedge on land. The sediments of these Groups are characterized by sedimentary facies change and the complicated folding structure, which were formed by each uplift that subdivided the basement blocks (**Fig. 11**). The geological structure of the Neogene series in the Fuji River Valley dominates the uplift motion of the basement blocks (Shiba, 1991). Assuming that the geological structure on the land side of Suruga Bay extends to the south side of the Nankai Trough, the geological structure of the accretionary wedge is thought to be formed by the uplift motion of the basement blocks.

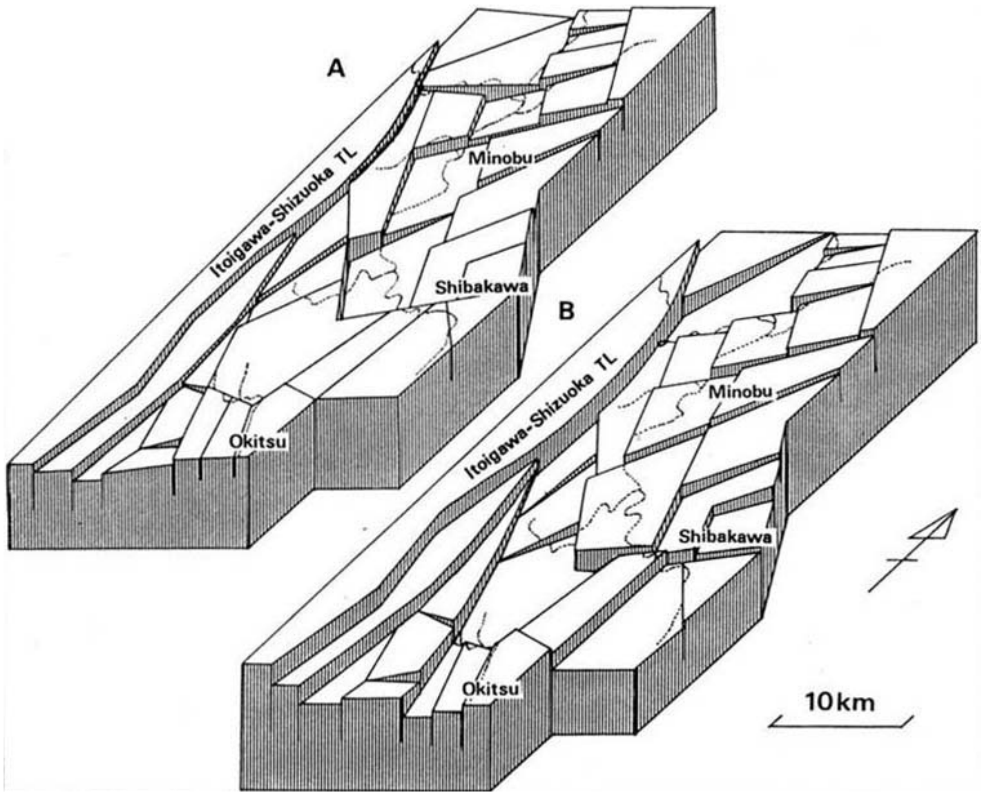

Fig. 11. Bird's eye view from the southeast direction of the underground basement blocks of the Neogene series in the Fuji River Valley estimated from the folding structure of the Neogene series (Tsunoda et al, 1990). A is for the sedimentary phase of the Minobu Formation of the Fujikawa Group (before 8.5 Ma of the late Miocene), and B is for the later period of the Iitomi Formation of the Fujikawa Group (after 8.5 Ma).

According to plate tectonics, the trench is supposed to be where the plate sinks. However, as it is obvious that a large-scale uplift on the land side should be considered that the crust on the land side was pushed out (or thrusted) to the ocean side. Also, the facts that the island arc and the trench are formed as a pair, and the recent earthquakes and volcanoes are present together, indicate that the island arc and trench were formed by recent activity. In other words, the island arc began to be formed from the late Miocene epoch (about 11 Ma ago), so the trenches also began to be formed in the same way, and the arc-trench system as well. The earthquake and volcanic activities as seen today also started from the late Miocene. Therefore, if the crustal deformation had really occurred by plate movement, the plate tectonics must have started since the late Miocene, not before that.

Formation of the Japanese Islands and the rising sea level

If we look at the geological structural zones of the southwest Japanese arc, it can be classified into four zones; A to D Zones (**Fig. 12**) in ascending order. A zone is consisting of the rock formations of the Proterozoic eon and the early Palaeozoic era (Hida Belt (1)) and the metamorphic rocks metamorphosed in the Carboniferous period (Hida marginal Belt (2)). B Zone is consisting of the formations of the late Paleozoic era of the Akiyoshi Belt (3), the Suo Belt (4), the Maizuru Belt (5), and the Ultra-Tanba Belt (6). C Zone consists of the Triassic to the Jurassic formations widely distributed from the Inner Zone (Mino Belt (7)) to the Outer Zone (Chichibu Belt (8)). The Ryoke Belt (9) and the Sanbagawa Belt (10) of C Zone are the metamorphic rocks of the Mino and Chichibu Belts, respectively, and are included in the Mino and Chichibu Belts. D Zone consists of the Late Cretaceous to Paleogene clastic formations of the Shimanto Belt (11) distributed in the Outer Zone.

I consider that the geological structural zones of the Southwest and the Northeast Japanese arcs are basically same. In the Southwest Japanese arc, A Zone (Hida Belt and Hida marginal Belt), B Zone (Akiyoshi Belt etc.), C Zone (Mino Belt and Chichibu Belt, etc.), and D Zone (Shimanto Belt) are arranged from the Sea of Japan side to the Pacific Ocean side. But in the Northeast Japanese arc, although the Sanbagawa Belt is unclear, it is distributed from the Ryoke Belt of C to D Zones. In the Southwest Japanese arc D Zone is distributed in the present terrestrial area, but in the Northeast Japanese arc D Zone is distributed in the continental slope at the Pacific Ocean side.

In the Southwest Japanese arc, D Zone, the northern part of the Shimanto Belt, is distributed continuously from the southeastern part of the Kyushu to the Akaishi Mountains, including the southern part of the Shikoku, the southern part of the Kii Peninsula, the Akaishi Mountains to the Kanto Mountains. In the Southwest Japanese arc, the northern part of D Zone uplifted to become the land after the Middle Miocene period, but in the Northeast Japanese arc D Zone did not become land, most of which had been lying under the sea floor of the continental slope.

D Zone of the Northeast Japanese arc corresponds to the Yezo Sedimentary Basin (Ando, 2005), most of which distributes at 2,500 to 3,000 m below the present sea level. The Yezo Sedimentary Basin was a vast land area where swampy land and meandering rivers developed from the Late Cretaceous to the Paleogene. On the contrary, the sediments of the Shimanto Belt of the Southwest Japanese arc were deposited in the continental slope and submarine fan. In other words, in D Zone from the Late Cretaceous to the Paleogene, the Northeast Japanese arc had been relatively raised than the Southwest Japanese arc. However, after the Miocene, D Zone of the Southwest Japanese arc turned to uplift. In the Northeast Japanese arc, the amount of uplift was small against the rise of sea level, and D Zone of the Northeast Japanese arc sunk in the ocean.

The uplift from the Sea of Japan side of the Southwest Japanese arc occurred in geological structure of A to D Zones, and the strata of the younger period were deposited in order toward the Pacific Ocean side. There was a shallow ocean in the early Paleozoic era from the Silurian to the Carboniferous period at the periphery of A Zone, which was mainly the Proterozoic basement rock distributed in and around the Sea of Japan. A Zone was uplifted due to the Variscan Orogeny that occurred during the Carboniferous period. Then, due to the uplift of the A Zone, the strata of B Zone of the Carboniferous to Permian period, such as coral reef limestone, accumulated on the outside of A Zone. Whereas, B Zone was uplifted in the Late Permian to Early Triassic. Metamorphic and igneous rocks distributed along the uplifted B Zone, such as the Suo Belt (or the Sangun Belt), were formed.

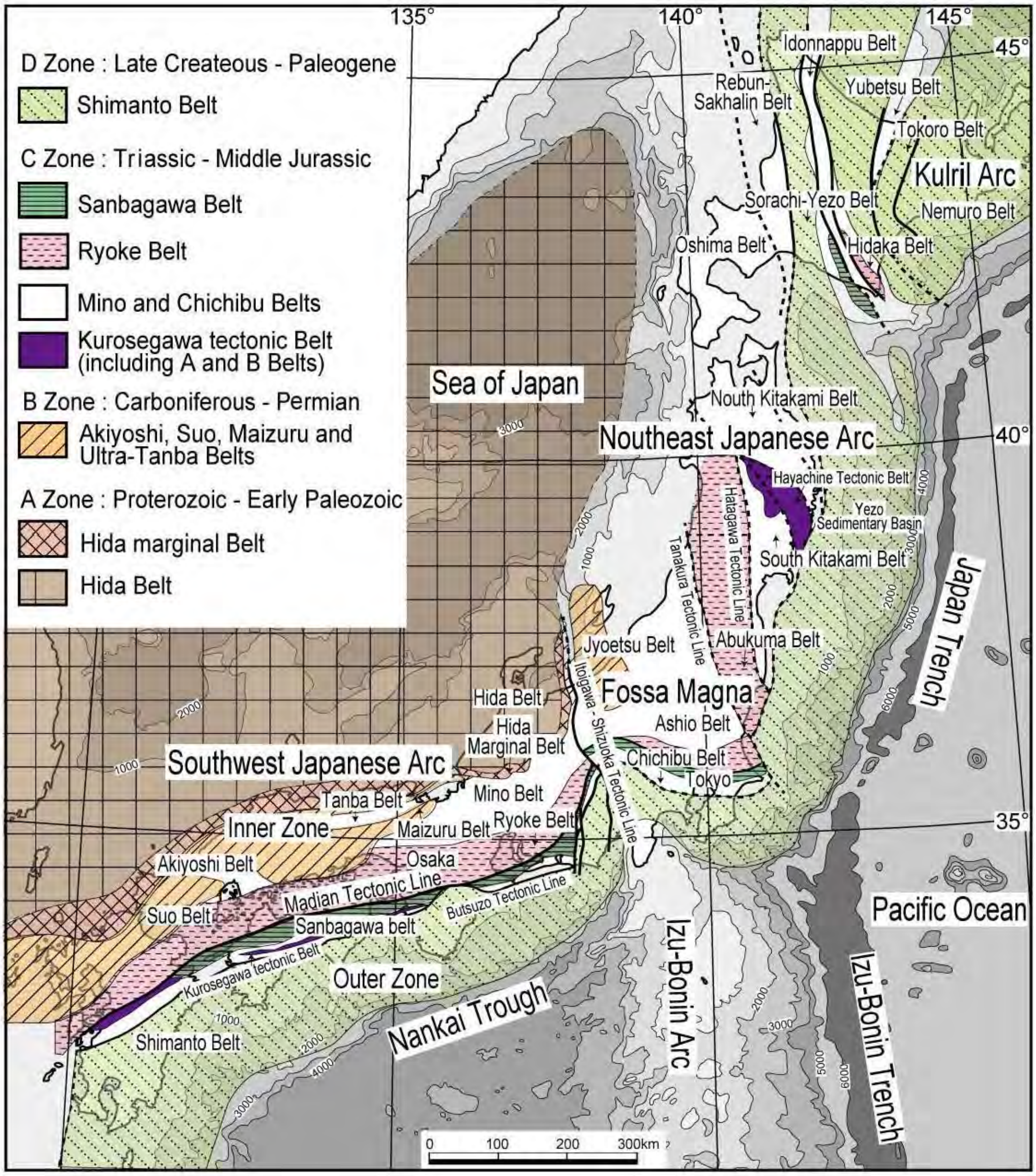

Fig. 12. The geological structure zones of the Japanese islands (Shiba, 2017). The Japanese islands is constituted of four of the A to the D geological structure zones.

On the Pacific side of the raised B Zone, there is C Zone that consists of Triassic to the Middle Jurassic chert, mudstone, sandstone, basaltic lava (called greenstone) and so on. The rocks form the Tanba Belt, the Mino Belt, the northern Chichibu Belt, the southern Chichibu Belt and the like. The formations of C Zone probably widely distribute under the Cretaceous groups of D Zone in the geological cross section of the Pacific side of the Southwest Japanese arc (**Fig. 13-1**) and the Northeast Japanese arc: It is considered that the C Zone sediments widely spread the seafloor of the Pacific Ocean across the trenches.

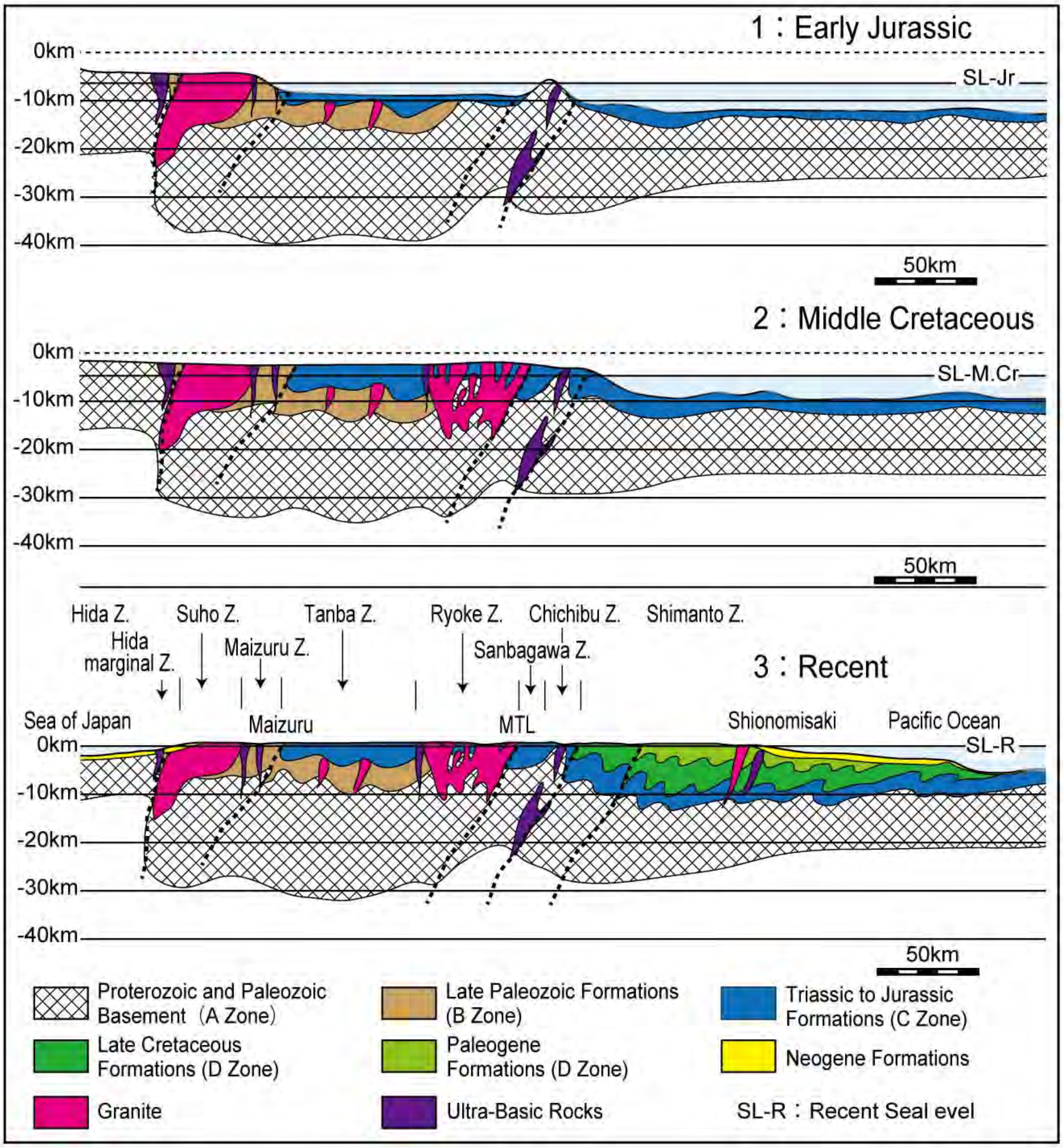

Fig. 13. Geological sections of the southwest Japanese arc and its formation process (Shiba, 2017). "3; Recent" is cited from Ichikawa et al. (1970). The Triassic to the Jurassic formations (sandstone, mudstone, chert and basalt lavas), have been alleged to be the Jurassic accretionary complex, but they are *in situ* sediments supplied from the Japanese Islands to the ocean floor of the Pacific Ocean.

The seafloor in the eastern side of the Japan Trench consists of Jurassic red chert and basalt lava, which are assumed by the Plate Tectonics to have deposited or erupted in the East Pacific Ridge and moved to the Japan Trench. However, the seafloor formation in the eastern slope of the Japan Trench has same age as that of C Zone, and the formation of C Zone includes red chert and basalt lava erupted in deep seafloor. Therefore, the formation of C Zone is not an accretionary wedge, but it has been originally developed in the Japanese Islands. In the Jurassic, the sea level was considered to be 5,000 to 6,000 m lower than the present, and the sea level had risen more than 1,000 m therefrom. During the Jurassic transgression period, little clastic deposit was supplied from the land area, and red clay (red chert) was deposited on the deep seafloor.

From the Early to the Late Cretaceous, the magmatic activity that formed the granite in the Inner Zone along the Median Tectonic Line (MTL) became active, which caused the Inner Zone to uplift on a large-scale. The low-pressure type metamorphic rock Belt (Ryoke Belt) was formed inside of the MTL, and the low temperature / high pressure type metamorphic rock Belt (the Sanbagawa Belt) was formed by the pressure due to uplifting extruded to the outer side of the MTL. Since the sea level rose by about 1,000 m even in the Early Cretaceous period, the Outer Zone side became a relatively deep seafloor and was formed a large sedimentary space (**Fig. 13-2**).

In the Late Cretaceous and the Paleogene periods when the amount of the sea level rise decreased, a large amount of sediment from the land area filled the sedimentary basins in front of the land. The Shimanto Belt of the Southwest Japanese arc was formed in the continental slope and the submarine fan, and the Shimanto Belt of the Northeast Japanese arc (Yezo Sedimentary Basin) was formed by the sediments which covered a vast land including rivers and shallow water.

In the Miocene, the Southwest Japanese arc began to uplift in its entirety, but the Northeast Japanese arc had not uplifted. As a result, the land on the Pacific side of the Northeast Japanese arc was submerged to the seafloor due to the rising sea level, but the Pacific side of the Southwest Japanese arc uplifted to form mountainous ranges. In addition, since the seafloor of the Sea of Japan did not rise mostly after the Late Cretaceous, it submerged into a deep sea without its southern area.

From the late Miocene, a large-scale uplift of the arc occurred, and the arc-like present Japanese Islands emerged. The central mountains which correspond to the backbone of the island arc were formed, which divided the island arc forming the Sea of Japan side and the Pacific side. Clastic sediments were supplied to both sides of the seafloor. On the Pacific side, these deposits were supplied to the trench slope. The sea level at that time was 2,000 m lower than the present sea level. The geological structure zone of the eastern part of the Southwest Japanese arc in the southern part of Fossa Magna curved toward the north, it is considered to be due to the curvature by the uplift of the Izu-Bonin arc in the north-south direction. It is thought that curving toward the north of the Southwest Japanese arc was formed after the Cretaceous.

A large-scale uplift of the Japanese Islands occurred in the early Pleistocene period (1.8 Ma); mountain ranges were uplifted, alluvial fans were formed from the coast to the continental slope, and sediments were supplied to the lower part of the continental slope. Furthermore, since 400 Ka ago in the middle Pleistocene, thrust faults became active that pushed the land out to the Pacific Ocean side. It was accompanied by a massive and rapid uplifting activity and absolute rise of the sea level by about 1,000 m at the same time, which have formed the present arc-trench trending topography (**Fig. 13-3**). Its activity is still continuing.

Conclusion

Suruga Bay has been formed by a combination of a large-scale uplift with thrust faults and an absolute rise of sea level (about 1,000 m) since about 400 Ka ago. As a result, the Suruga Bay Central Channel and the Senoumi Basin were left from the uplift and the sea level rise and submerged. The uplift of the crust and the sea level rise that occurred after about 400 Ka ago have formed the present topography of the world. The present land has risen more than the sea level rise, while the seafloor has been submerged by the sea level rise.

In order to form a stratum, it is necessary to uplift the crust and raise the absolute sea level, which means the Micro-Expanding Earth. In the Jurassic period, the sea level was 5,000 to 6,000 m lower than the present, and the distribution of continents and oceans is considerably different from that of the present. After that the strata and the topography were formed due to uplift of the crust and rising of the sea level by the eruption of the flood basalt on the ocean floor. From the Cretaceous, the plutonic igneous activity and the uplift of the continental margin of the Pacific Rim began. In the Late Miocene, arcs began to be formed by uplift of the crust, and ultimately the present topography has been formed by a large-scale uplift and the sea level rise by about 1,000 m since 400 Ka ago.

Acknowledgments: In preparation of this paper, Dr. Dong R. Choi helped me bring the paper to a publishable form. I am encouraged by Dr. Michihei Hoshino, an Honorary Professor of Tokai University. Dr. Takao Yano who is the executive director of the celebrative symposium for the publication of the Japanese version of the B. I. Vasiliev's “Geological Structure and Origin of the Pacific Ocean”, held on June 24, 2017 in Tokyo. As for Fig. 2, I would like to thank Mr. Tatsuro Chiba who provided the map, and Asia Air Survey Co., Ltd. who gave me a special approval.

References

Ando, H., 2005. Geologic setting and stratigraphic correlation of the Cretaceous to Paleocene Yezo fore-arc basin in Northeast Japan. *Jour. Japan. Assoc. Petrol. Technol*., v. 70, p. 24-39. (In Japanese with English abstract).

Bassinot, F.C., Labeyrie, L.D., Vincent, E., Quidelleur, X., Shackleton, N.J. and Lancelot, Y., 1994. The astronomical theory of climate and age of the Brunhes Matsuyama magnetic reversal. *Earth Planet. Sci. Letter*, v. 126, p. 91-108.

Haq, B. U., Hardenbol, J. and Vail, P. R., 1987. Chronology of the fluctuating sea levels since the Triassic. *Science*, v. 235, 1156-1166.

Hoshino, M., 1962. The Pacific Ocean. *Assoc. Geol. Collab. Japan*, 136p. (In Japanese).

Hoshino, M., 1981. Basaltic stage. *Jour. Marine Sci. Technol., Tokai Univ*., v. 16, p. 65-68. (In Japanese with English abstract).

Hoshino, M., Izu, S., Hanada, M. and Anma, K., 1982. Geology of the Senoumi-bank, Suruga Bay. *Jour. Marine Sci. Technol., Tokai Univ*., v. 15, p. 109-121. (In Japanese with English abstract).

Hoshino, M., 1991. The Basaltic Stage. Basic Concept of Geological Science. Tokai Univ. Press, 456p. (In Japanese with English abstract).

Hoshino, M., 2014. The History of Micro-Expanding Earth - History of the Earth from viewpoint of Sea Level Rise-. E. G. Service Press, 234p.

Hsü, K. J., Montadert, L., Bernoulli, D., Cita, M. B., Erickson, A., Carrison, R. E., Kide, R. B., Melieres, F., Muller, C. and Wright, R., 1977. History of the Mediterranean salinity crisis. *Nature*, v. 267, p. 399-403.

Ichikawa, K., Fujita, Y. and Shimazu, M., 1970. History of Geological Structure Development in the Japanese Islands. Tsukiji Shokan, 232p. (In Japanese).

Inouchi, Y., Okuda, Y. and Yoshida, F., 1978. On the age of formation of upper continental slope configuration in the south of the Kii Straits. *Jour. Geol. Soc. Japan*, v. 84, p. 91-93. (In Japanese with English abstract).

Okamura, Y., Yuasa, M. and Kuramoto, S., 1999. Explanatory notes of Geological map Suruga Wan. Marine Geology Map Series, 52, Geological Survey of Japan, 44p. (In Japanese with English abstract).

Shiba, M., 1988. Geohistory of the Daiichi-Kashima seamount and the Middle Cretaceous Eustacy. *Sci. Rept. Nat. Hist. Mus., Tokai Univ*., no. 2, 69p., 10pls.

Shiba, M., 1991. The Geological structure of the southwestern part of the south Fossa Magna area – Geology of the Shimizu and Ihara districts in Shizuoka Prefecture, central part of Japan, *Monogr. Asso. Geol. Collab. Japan*, no. 40, 98p., 3maps, 5pls. (In Japanese with English abstract).

Shiba, M., 1992. Eustatic rise of sea-level since Jurassic modified from Vail's curve. *Abst. 29th IGC (Kyoto)*, v. 1-3, p. 95.

Shiba, M., 1993. Middle Cretaceous Carbonate Bank on the Daiichi-Kashima Seamount at the junction of the Japan and Izu-Bonin Trenches. Simo, T., Scott, B. and Masse, J-P., Eds. Cretaceous Carbonate Platform*, Amer. Assoc. Petrol. Geol. Mem*., no. 56, p. 465-471.

Shiba, M., 2016a. How was the Suruga Bay formed? *Jour. Fossil Research*, v. 49, p. 3-12. (In Japanese).

Shiba, M., 2016b. The First Study of Paleontology. Tokai Univ. Press, 190p. (In Japanese).

Shiba, M., 2017. Formation of Suruga Bay - Large-scale uplift of arc and sea level rise. Tokai Univ. Press, 406p. (In Japanese).

Shiba, M., Hisamatsu, Y., Okazaki, H., Watanabe, T. and Shiba, H., 2012. Fossil foraminiferal assemblages and the transition of depositional environment of the Middle Pleistocene Negoya Formation in the Udo Hill, Shizuoka City, central Japan. *Sci. Rep. Mus. Tokai Univ*., no. 11, p. 23-41. (In Japanese with English abstract).

Tsunoda, F., Shiba, M. and Suzuki, K., 1990. Deformation of the shallow seated crust in the south Fossa Magna - Formation of the non-symmetrical anticlines in the Fuji River Valley -. *Mem. Geol. Soc. Japan*, no. 34, p. 171-196. (In Japanese with English abstract).

Uchupi, E., 1975. Physiography of the Gulf of Mexico and Caribbean Sea. Nairn, A. E. M. and F. G. Stehli, Eds. The Gulf of Mexico and Caribbean, Prelnum Press, p. 1-64.

Vail, P. R., Michum, R.M.Jr. and Thompson, III S., 1977. Global cycle of relative changes of sea level. In: Payton, C. E., Ed. Seismic Stratigraphy-Application to Hydrocarbon Exploration. *Amer. Assoc. Petrol. Geol. Mem*., no. 26, p. 83-97.

Vasiliev, B. I., 1991. Main features of the geological structure of the northwest Pacific. Translated by K. Oshide, M. Hanada and M. Ishida, Earth Science Research Center, 204p. (In Japanese). [Translated from Васильев, 1988. Основные черты голгического строения север-западной части Тихого океана.Владиосток: ДВО АН СССР, 192c.]