



島弧の移動と合体のダイナミクス： 北西太平洋縁辺における構造論的事例

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A plate reconstruction model of the NW Pacific region since 100 Ma

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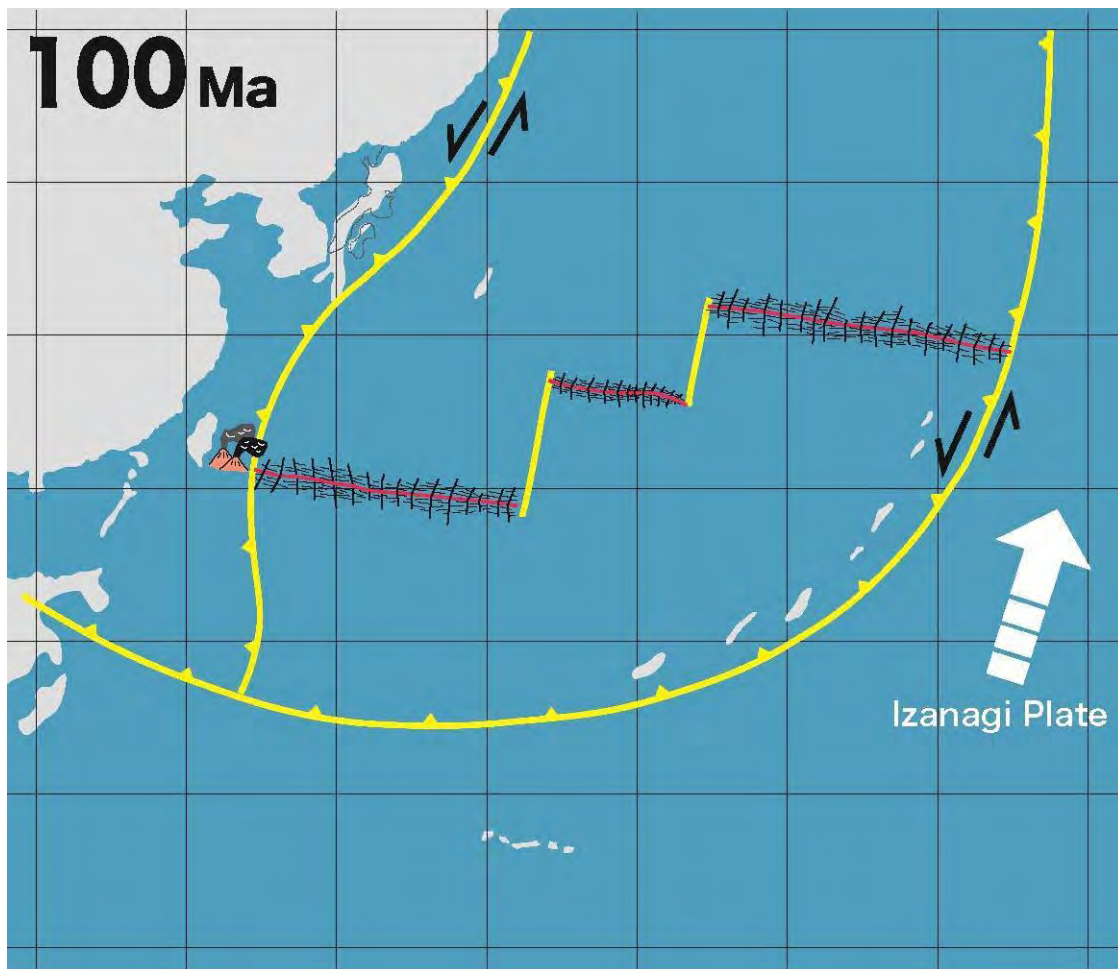
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Abstract

A plate tectonic model of the northwestern Pacific region since 100 Ma is presented in this document. The evolution of the Pacific margin is viewed as a longstanding history of migration and amalgamation of allochthonous blocks onto the subduction zone. Such a process inevitably provoked diverse tectonic events. In order to reconcile paradoxical discrepancies in the docking process of arc fragments on the margin, the authors introduce a marginal sea plate with a spreading center that was alive in the Cretaceous. Oblique subduction of the ridge caused specific migratory igneous activity along the rim of the overriding plates, together with flips of shearing direction. Arc-trench systems upon the eastern and western sides of the marginal sea plate developed following different timelines and were eventually mixed up during the plate's closure that prompted formation of a coincident Oligocene clinounconformity widespread on the Eurasian margin. Since the demise of the hypothetical plate, the tectonic regime of the northwestern Pacific margin has been controlled by the growing processes, namely, the rotational history and modes of convergence of the Philippine Sea Plate.

Feel free to browse pages clicking on the embedded hyperlinks, and consider your just history of the circum-Pacific region from the Cretaceous to the present. To reconstruct the chronicle of the northwestern Pacific area since 100 Ma, numerous previous geologic works have been examined for the estimation of the whereabouts of continental fragments. It is, however, difficult to include all the information in this document. Please refer to the Chapter 5 (Tectonic synthesis: a plate reconstruction model of the NW Pacific region since 100 Ma) of our book "Dynamics of Arc Migration and Amalgamation: Architectural Examples from the NW Pacific Margin" published by InTech, for the full details of the model concept.



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We introduce a marginal sea plate between mother continent and major oceanic plates to construct a conciliatory model of varied timing of collision/amalgamation of the crustal blocks onto the continental rim and conspicuous magmatism probably related to ridge subduction. Around the present northwest Pacific region, governance of the Izanagi Plate heralded the beginning of Late Cretaceous, which was characterized by a quite rapid northerly movement (110 Ma; p.25 of [1]) provoking wrench deformation on the eastern boundary of the marginal sea plate.

Eastern margin of Eurasia was a site of voluminous igneous activity during the Late Cretaceous, which shows a clear northeastward-younger trend. Kinoshita's [2] original hypothesis assuming an effect of the Kula-Pacific ridge subduction is noteworthy. However, pathway of the Kula-Pacific ridge in his theory does not accord with Engebretson's [1] plate reconstruction. Instead, we assume a spreading center within the newly introduced marginal sea plate. In our model cartoons, the ridge moves in a pace concordant with the time-progressive plutonism on the continental margin. It is plausible that rapid northerly migration of the Izanagi-Pacific ridge caused short-lived intensive

igneous activities during the Late Cretaceous along the eastern boundary of the marginal sea plate (including major portion of the present northeast Japan forearc), which was interpreted as the Farallon-Izanagi ridge effect by Kinoshita [2].

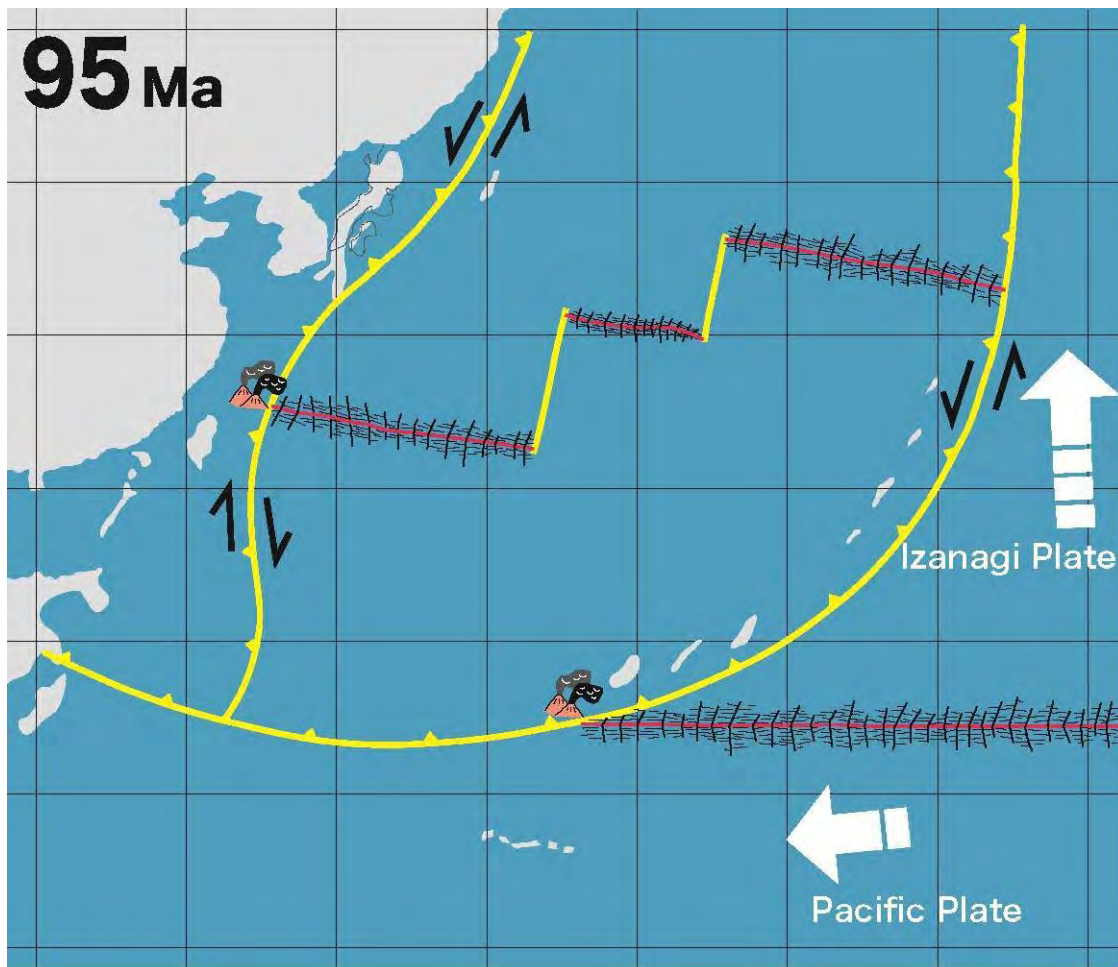
Based on a detail stratigraphic study of the Late Jurassic to Early Cretaceous Sorachi Group in central Hokkaido, Takashima et al. [3] proposed a tropical to subtropical origin of the terranes in the present northern territory based on frequent occurrences of oolitic limestone and other paleontological evidences. Although precise paleoposition of the landmass still remains difficult to estimate, their findings are regarded as an essential constraint of the reconstruction model.

Based on an elaborate work of structural geology in northeast Japan, Sasaki [4] restored a pre-deformation configuration of its forearc under a strong sinistral shear stress during the Early Cretaceous. It must be related with extremely rapid northerly motion of the Izanagi Plate in the period, and Sasaki's work provides us with a clue to estimate an effective range of wrench deformation under an intensive tectonic episode on a convergent margin.

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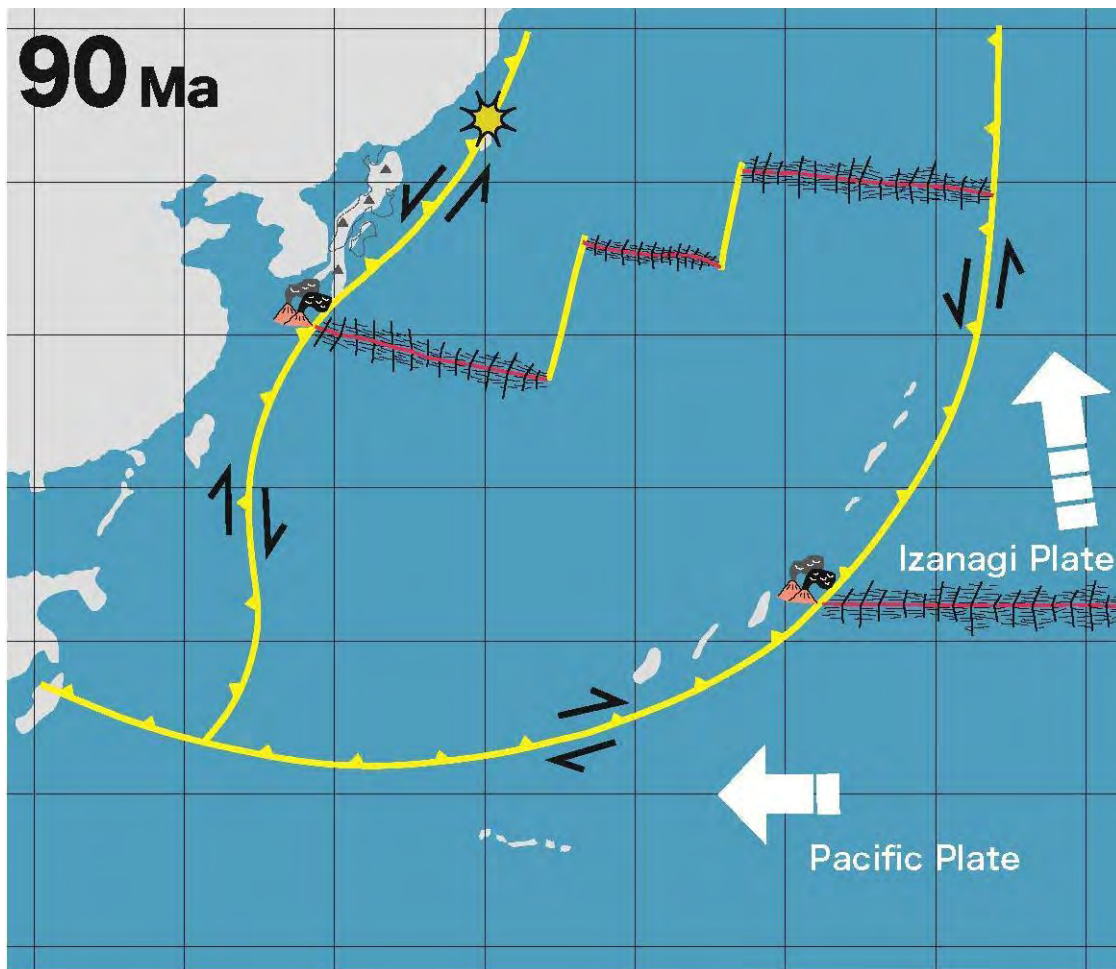
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It was clearly shown that the muddy sediments of the Late Cretaceous Yezo Group obtained from the Oyubari area in central Hokkaido has a geographical affinity to the mother Eurasian continent based on Tamaki and Itoh's [3] paleomagnetic analyses. We, hence, assume that a part of crustal blocks composing the present Japanese Archipelago has long been settled on the margin of the mother continent, and placed upon the western convergent boundary of the newly introduced marginal sea plate.

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(including a major portion of the present northeast Japan forearc), which Kinoshita [2] originally interpreted as the Farallon-Izanagi ridge effect.

It should be noted that the hypothesis submitted by Ueda and Miyashita [3] was a pioneer to explore the origin of polymictic lithological blocks upon a collision front. Their theory leads us to imagine intensive deformation event in the Late Cretaceous on the Eurasian margin, which faced on the northwesterly moving marginal sea plate.

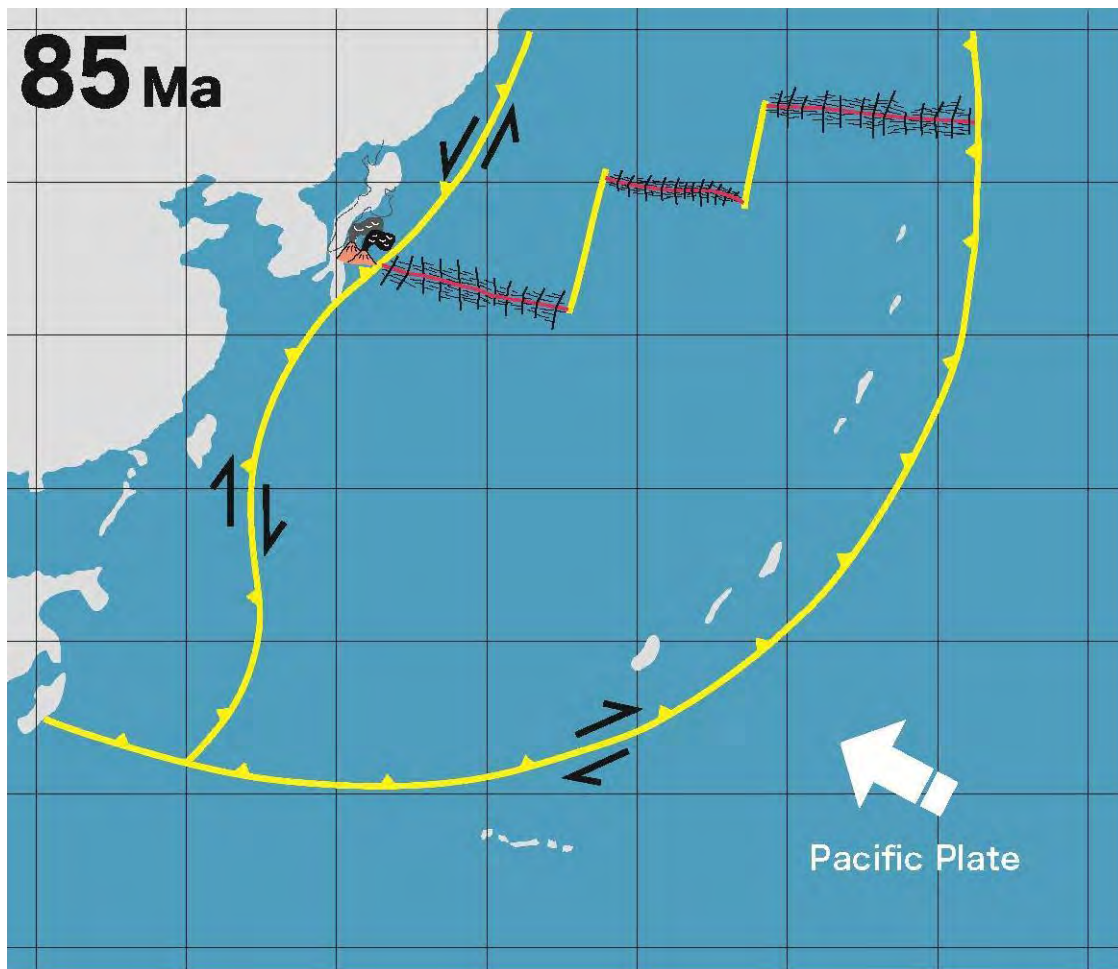
Collision of a remnant arc mentioned above inevitably provoked strong deformation of the forearc region. Tamaki and other's [4] geochemical expedition clarified that the indented rim of the continent was intensively deformed, which is recorded as an anomalously rapid burial of the Yezo forearc basin and a prompt exhumation accompanied with buildup of overturned structure. It is a significant tectonic episode in the Late Cretaceous, and we anticipate that some more geologic findings can be related with this event.

Not only the collision of a landmass on the northern portion of the continental margin, this period was marked by a growing influence of the spreading center of the marginal sea plate. Wallis and others [5] obtained an astonishing result that Lu-Hf ages of the eclogite samples obtained from the Sanbagawa metamorphic rocks in southwest Japan was centered at 89~88 Ma identical with Ar-Ar phengite ages of the same unit, which requires an extremely rapid exhumation of the metamorphosed terrane on the forearc. Their original concept was that the approaching Izanagi-Pacific ridge triggered uplift of the accretionary prism, and our alternative interpretation for the integrated thermo-chronological results is that the northerly moving spreading center of the hypothetical marginal sea plate caused popup of the island arc.

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The received wisdom is that southwest Japan was a stable component of the eastern Eurasian margin before the Miocene backarc opening of the Japan Sea. On such a condition, it is quite enigmatic that its deformation structure seems to indicate multiple shift of direction of shear through the Late Cretaceous. Tokiwa [2] has most explicitly described the sequence of stress-shear wobbles on the island arc based on a detailed analysis of deformation structure of an accretionary prism on its forearc. He suggested a flickering shift of sinistral-to-dextral (90~85 Ma) and dextral-to-sinistral (75~70 Ma) deformation upon just the same convergent margin. Northerly moving spreading center of the assumed marginal sea plate in our model acts as a toggle switch to solve the paradox,

namely, segments of the convergent margin on its both sides show opposite sense of shear as shown in our cartoons.

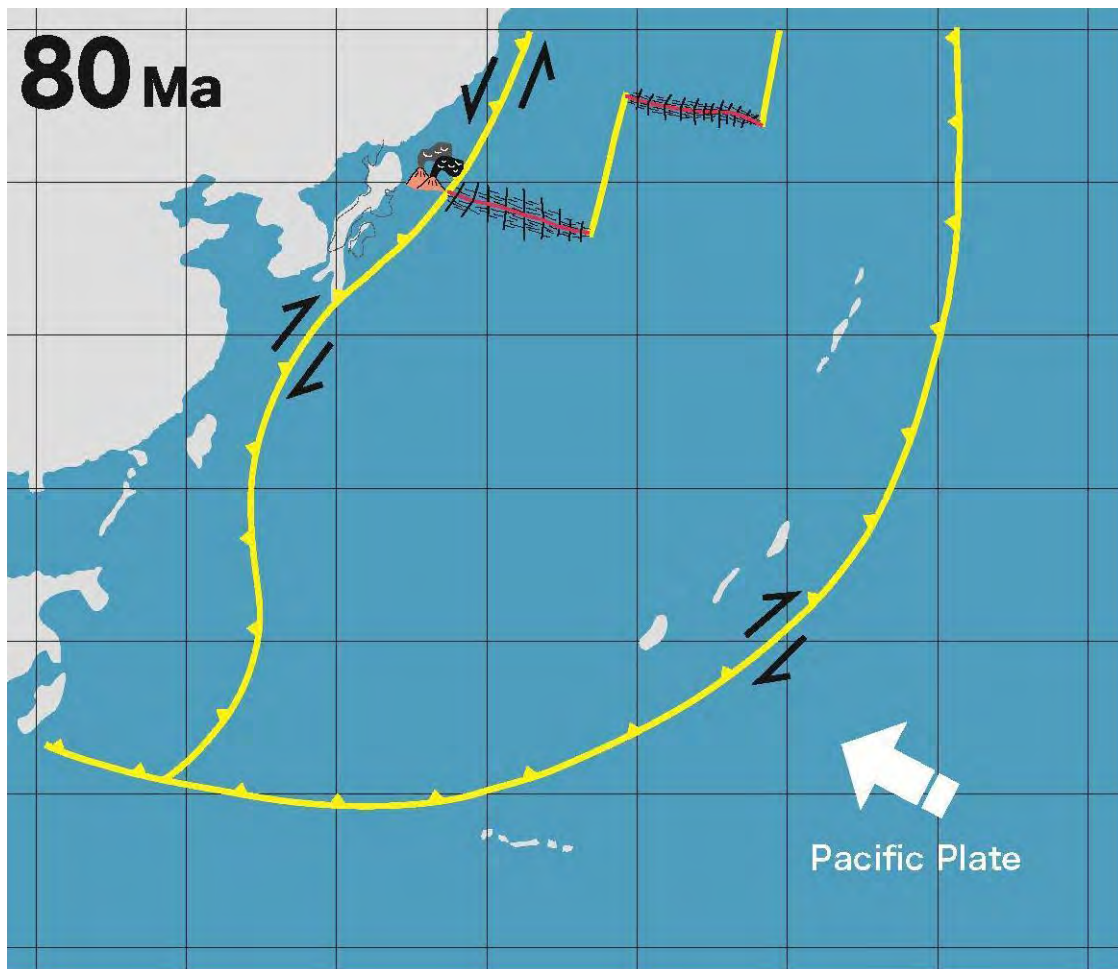
Westerly motion of the Pacific Plate in this period may have provoked right-lateral wrench deformation of the forearc of northeast Japan, as depicted by complex rotation sequence of a large pluton in Kamaishi revealed through paleomagnetic research of Itoh and others [3]. It seems that temporal changes in sense of oblique convergence of the oceanic plates affected whole of the forearc as presented by a paleomagnetic study of subsurface core samples cited below.

To evaluate rotational motions related to the forearc wrenching proposed in the previous structural studies, paleomagnetic measurements of core samples obtained from the MITI Sanriku-oki, an exploration borehole on the forearc shelf of northeast Japan, was executed by Itoh and Tsuru [4]. The Eocene and Late Cretaceous cores were successfully oriented based on correlation between bedding planes upon the core surface and side-wall imaging, or northing calibration referring to mean declination of secondary normal magnetization. Their directions of primary magnetization were corrected for tectonic tilting, and comparison with contemporaneous reference directions indicated 87° counterclockwise rotation between the late Campanian and Eocene, and thereafter 42° clockwise rotation. Although sequence of rotational motions is similar to that revealed for the pluton on land (cf. Itoh et al., [3]), sinistral wrenching seems to have lingered to later age on the shelf, which may be related to time-lag in fault activity.

References

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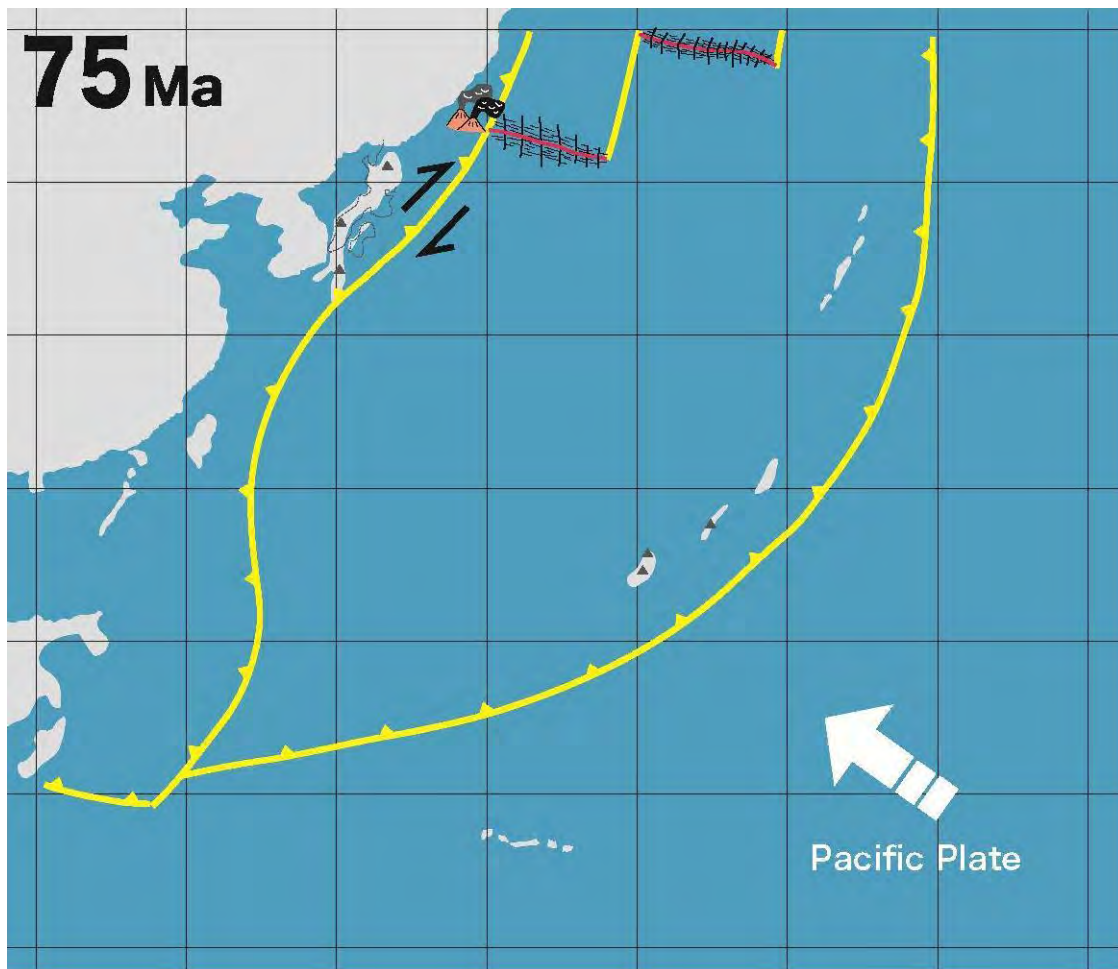
Low latitude origin of a certain part of the northeastern Japan arc was clearly indicated by paleomagnetic study by Tamaki and others [3] executed in south central Hokkaido. Their results infer that the Late Cretaceous Yezo Group may have deposited upon some remote places of “forearc” on both sides of the marginal sea plate.

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Throughout the terminal period of Cretaceous and early Paleogene, the Pacific Plate was characterized by northwesterly moderate convergence as depicted in a reconstruction at 65 Ma (p. 23 of [1]). Its motion vector was calibrated based on linear velocity tables (p. 38~41 of [1]).

Eastern margin of Eurasia was a site of voluminous igneous activity in the Late Cretaceous, which shows a clear northeastward-younger trend. Kinoshita's [2] original hypothesis assuming an effect of the Kula-Pacific ridge subduction is noteworthy. However, pathway of the Kula-Pacific ridge in his theory does not accord with Engebretson's [1] plate reconstruction. Instead, we assume a spreading center within the newly introduced marginal sea plate. In our model cartoons, the ridge moves in a pace concordant with the time-progressive plutonism on the continental margin. It is plausible that rapid northerly migration of the Izanagi-Pacific ridge caused short-lived intensive igneous activities during the Late Cretaceous along the eastern boundary of the marginal sea plate (including major portion of the present northeast Japan forearc), which was interpreted as the Farallon-Izanagi ridge effect by Kinoshita [2].

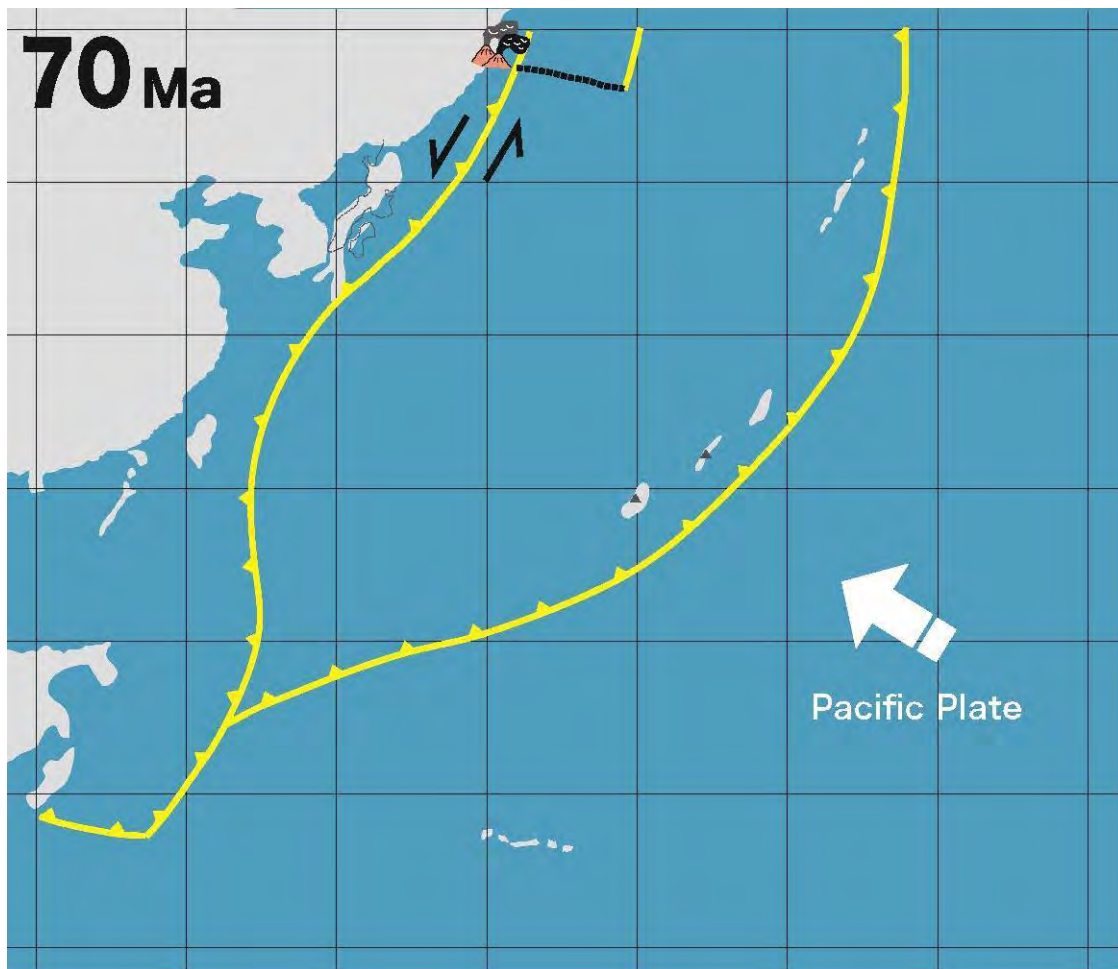
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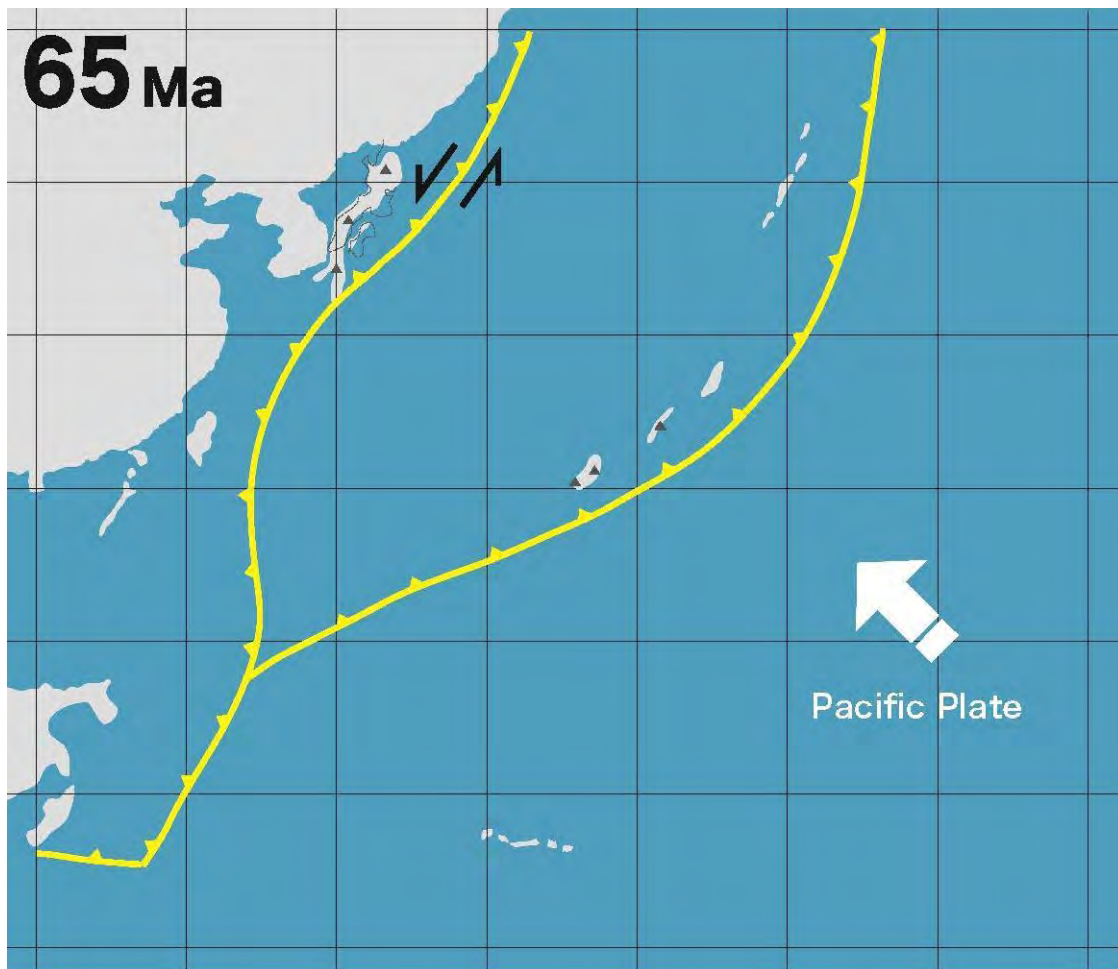
The received wisdom is that southwest Japan was a stable component of the eastern Eurasian margin before the Miocene backarc opening of the Japan Sea. On such a condition, it is quite enigmatic that its deformation structure seems to indicate multiple shift of direction of shear through the Late Cretaceous. Tokiwa [3] has most explicitly described the sequence of stress-shear wobbles on the island arc based on a detailed analysis of deformation structure of an accretionary prism on its forearc. He suggested a flickering shift of sinistral-to-dextral (90~85 Ma) and dextral-to-sinistral (75~70 Ma) deformation upon just the same convergent margin. Northerly moving spreading center of the assumed marginal sea plate in our model acts as a toggle switch to solve the paradox, namely, segments of the convergent margin on its both sides show opposite sense of shear as shown in our cartoons. At around 70 Ma, demise of the spreading center provoked a dextral-to-sinistral shift of shearing on the forearc of southwest Japan.

Considerable northward translation of a part of Sakhalin was shown through Bazhenov and others' [4] paleomagnetic study, of which paleolatitudes accord with convergent trajectory of the Pacific Plate. However, extensive paleomagnetic analyses by Weaver and others [5] revealed mixed origin of Sakhalin, namely, terranes having latitudinal affinity to Eurasian, North American and Pacific Plates. It was also suggested that systematic flattening of paleomagnetic inclinations may mimic northward migration of crustal blocks. Further verification including shallowing correction experiments are necessary to obtain a secure conclusion.

References

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Throughout the terminal period of Cretaceous and early Paleogene, the Pacific Plate was characterized by northwesterly moderate convergence as depicted in a reconstruction at 65 Ma (p. 23 of [1]). Its motion vector was calibrated based on linear velocity tables (p. 38~41 of [1]).

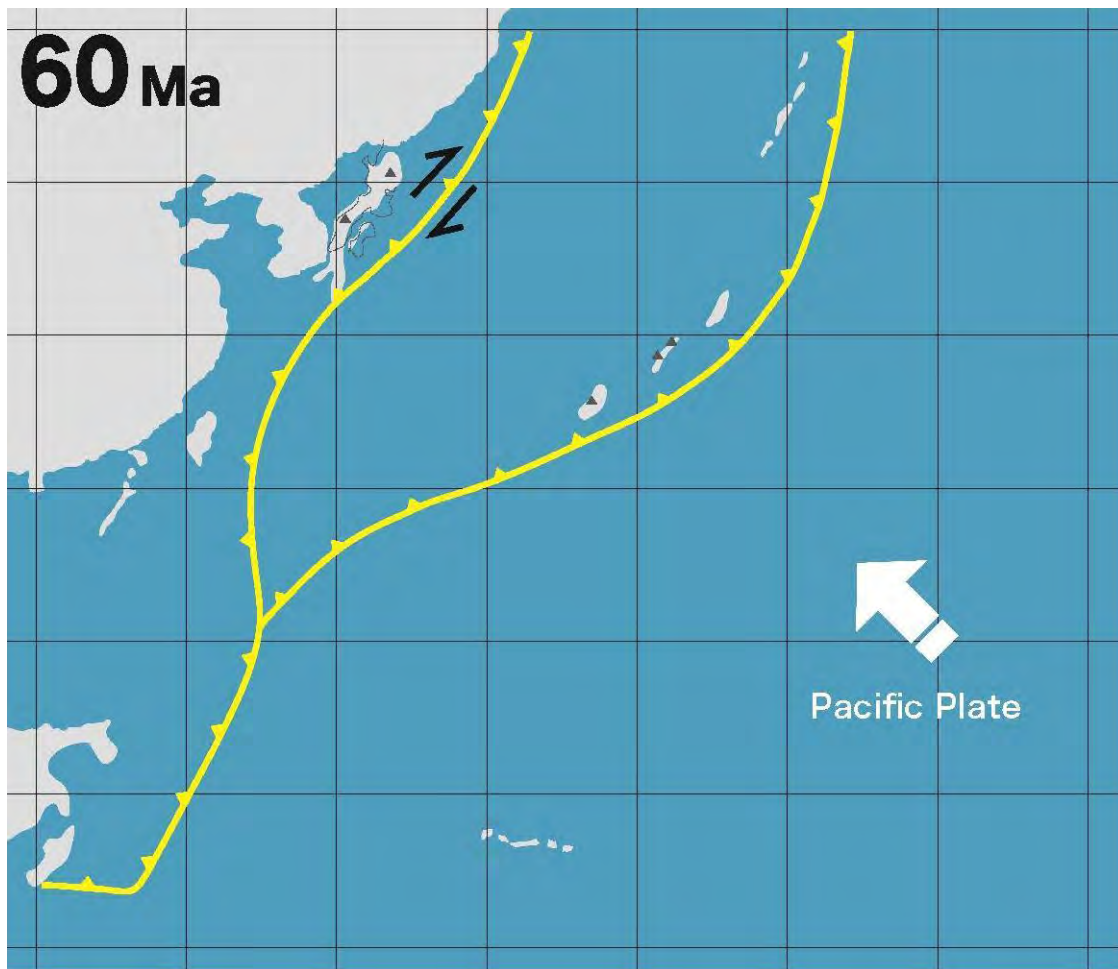
Careful paleomagnetic measurements executed on the latest Cretaceous to the early Paleocene volcanoclastic rocks by Otofujii and others [2] revealed tropical origin of a forearc component of northeast Japan. Their paleolatitudes deduced from paleomagnetic inclinations, however, are significantly lower than those expected from trajectory of the Pacific Plate. Our model implies that the studied landmass was on the southern part of the boundary between the marginal sea and Pacific Plates.

It is well known that a regional unconformity, so-called K/T Gap, developed in this period around the northwestern Pacific [3]. At the present, we have not found a drastic change in plate motion or continental collision related with the significant event.

References

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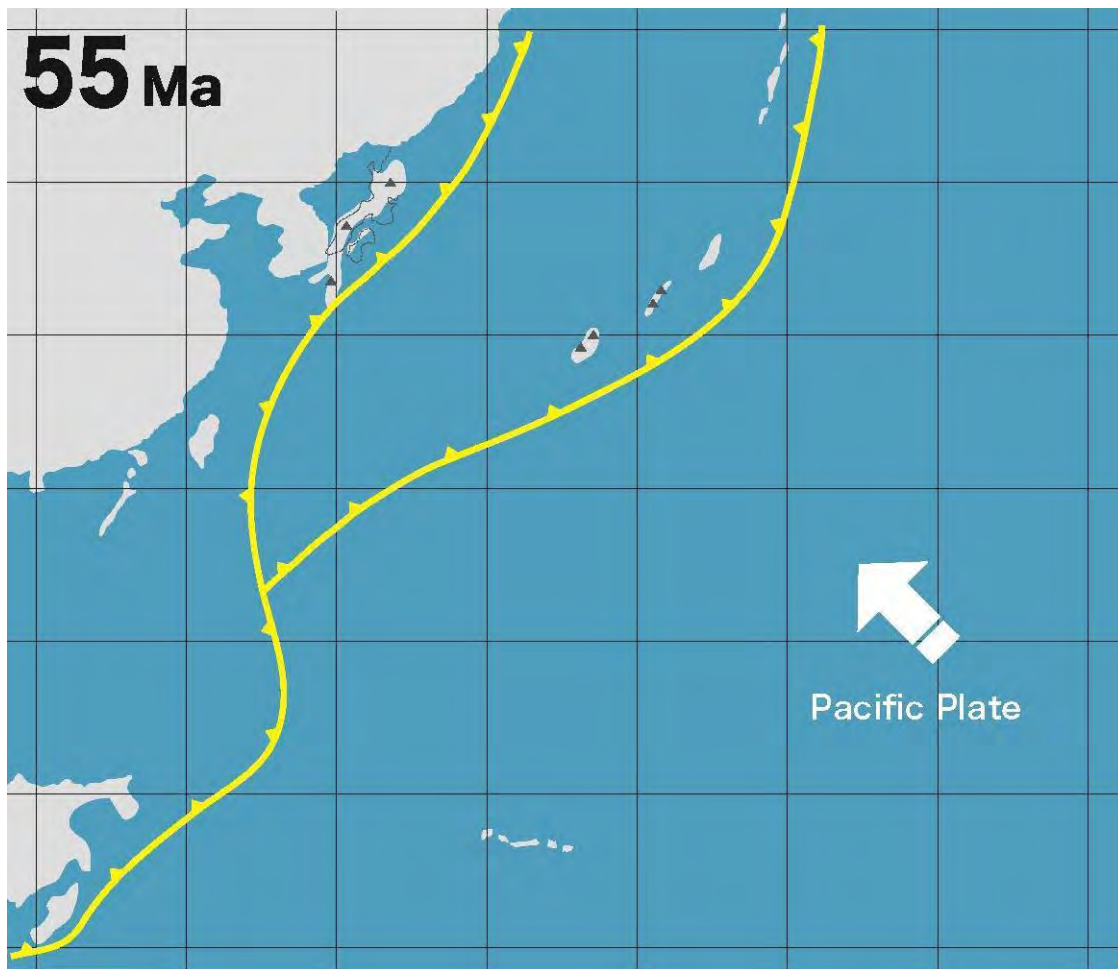
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A possible shift of shear direction from sinistral to dextral is shown in our reconstructions. Although the driving force of the transient stress state has not been identified, the early Paleogene is a period when an asthenospheric injection provoked crustal thinning and formation of intracontinental basins and deformation of the convergent margin [4]. Such an event may have triggered the change in stress state.

References

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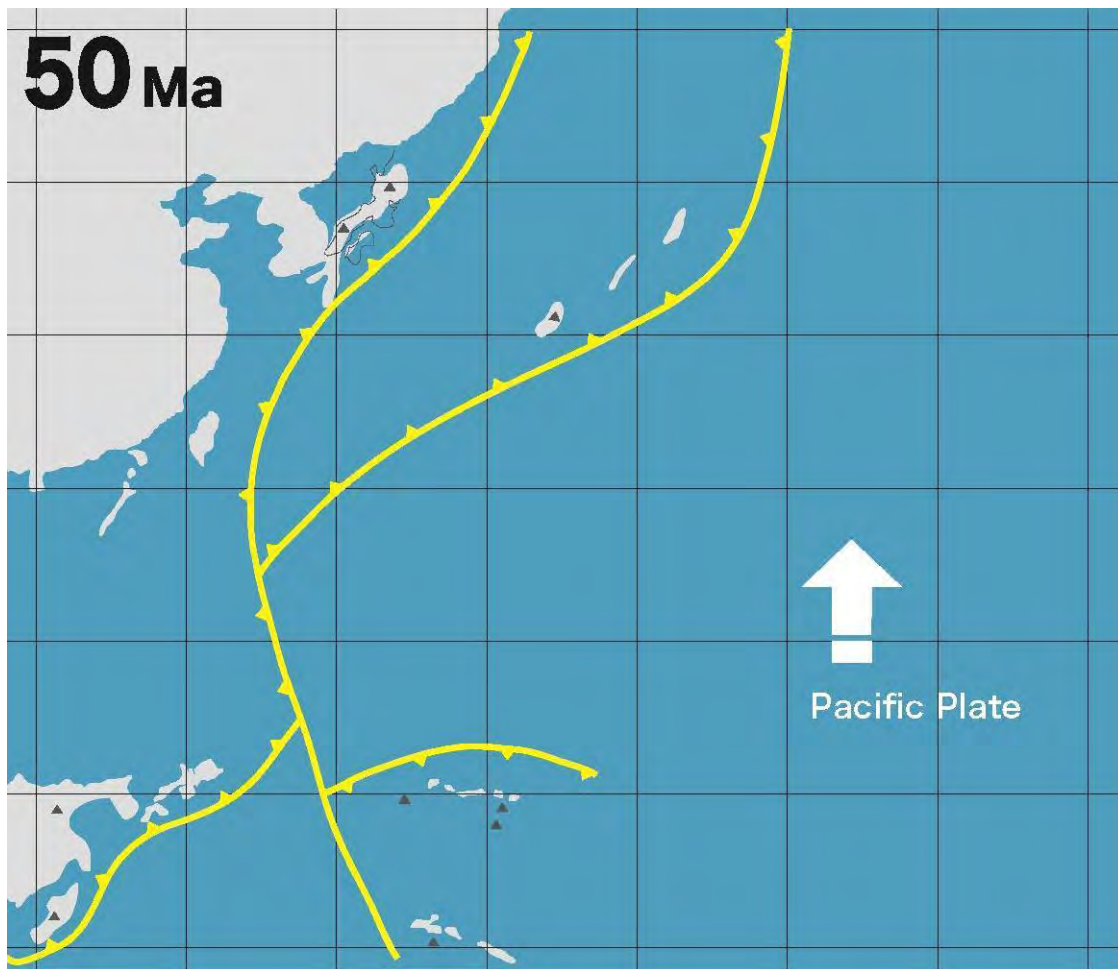
After extensive exhumation during the K/T Gap, another unconformity was formed between upper part of the Hakobuchi Group and the Haboro Formation [2].

In this period, a part of today's components of southeast Asia was confined adjacent to the approaching India, and spreading of marginal sea in the Pacific region remained stagnant [3, 4].

References

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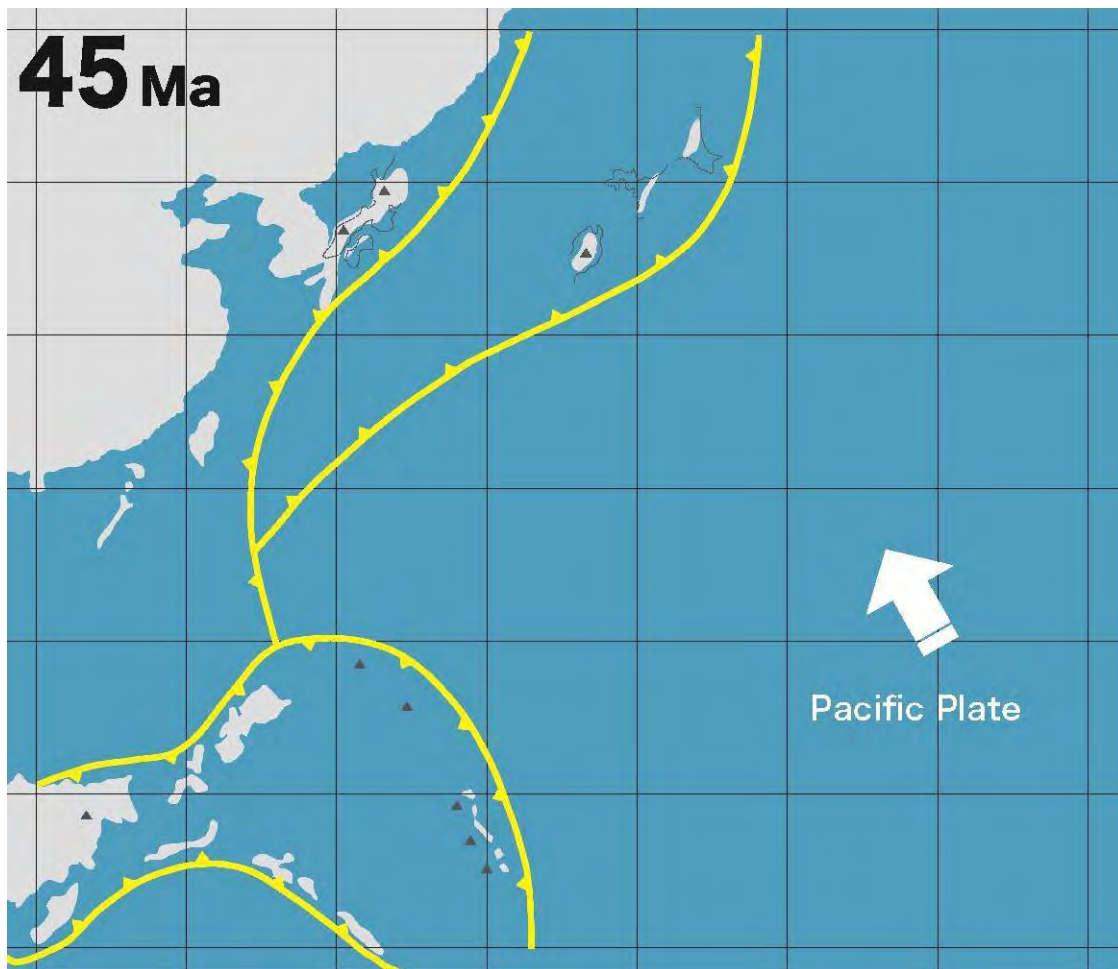
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The Philippine Sea Plate had begun to form in the equatorial Pacific region [3, 4].

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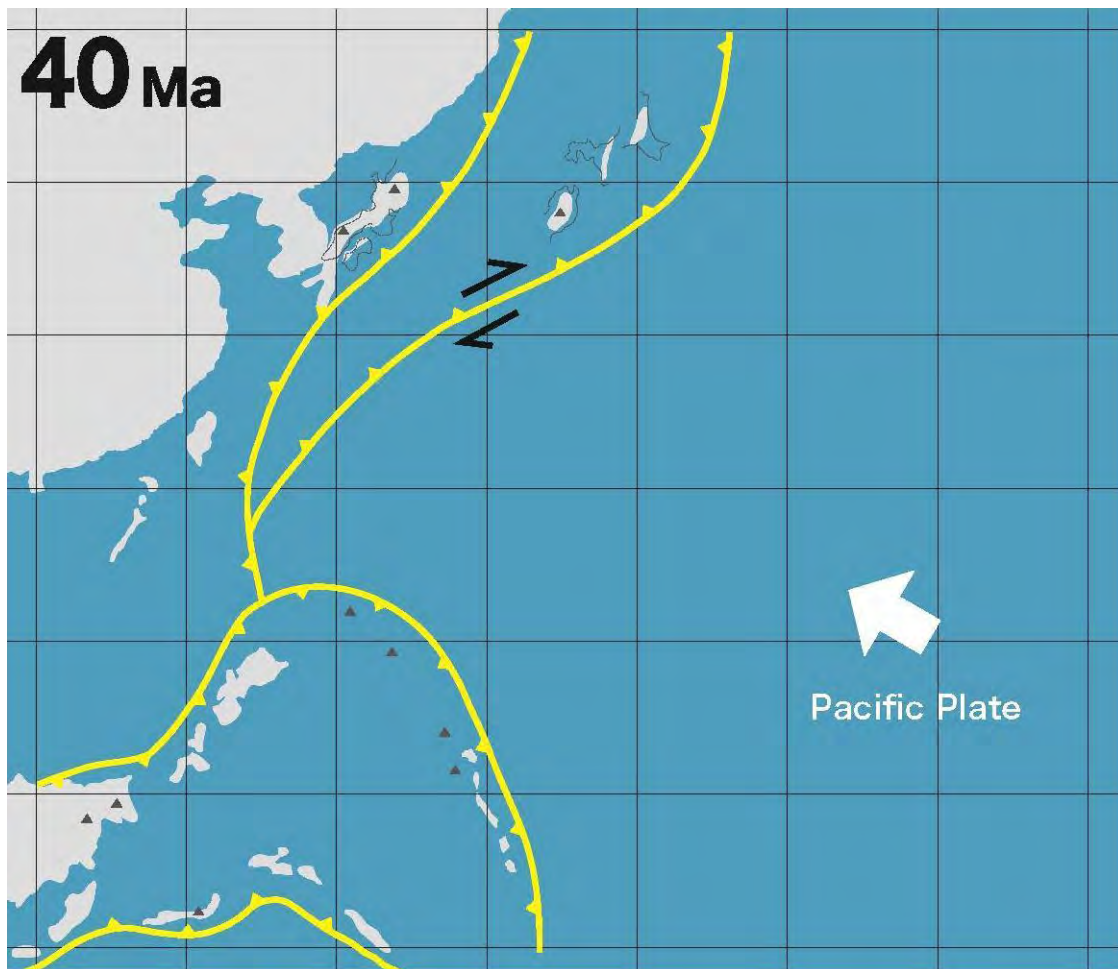
sedimentary basins throughout the Paleogene.

In the southern Pacific, Australia began to migrate northward, generating new convergent margins fringing around the Sundaland. Spreading centers in the Celebes Sea and Philippine Sea were active under a backarc setting [4, 5].

References

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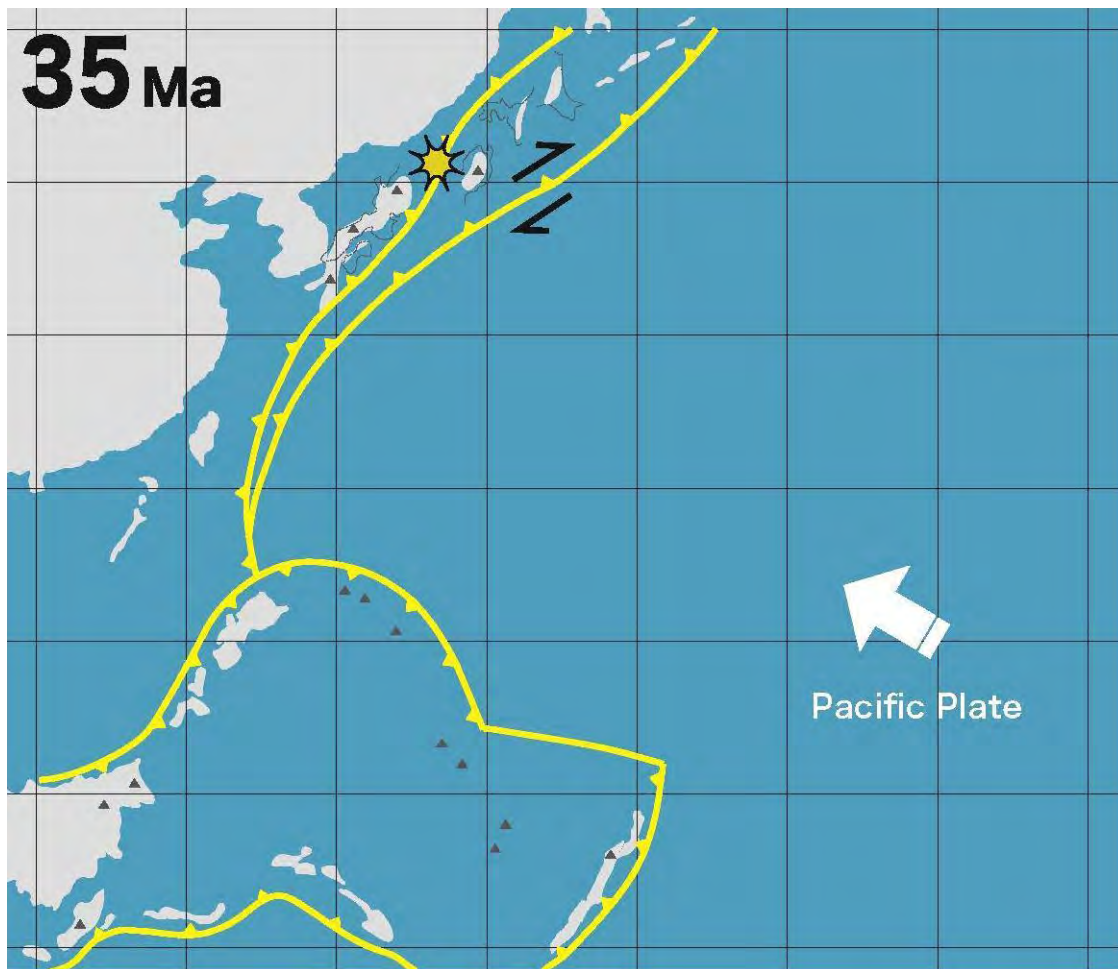
sedimentary basins throughout the Paleogene.

The proto-Philippine Sea Plate continued to expand. Azimuth of its spreading center had been fixed in east-west direction. To the west, India was about to collide against the Eurasia [4, 5].

References

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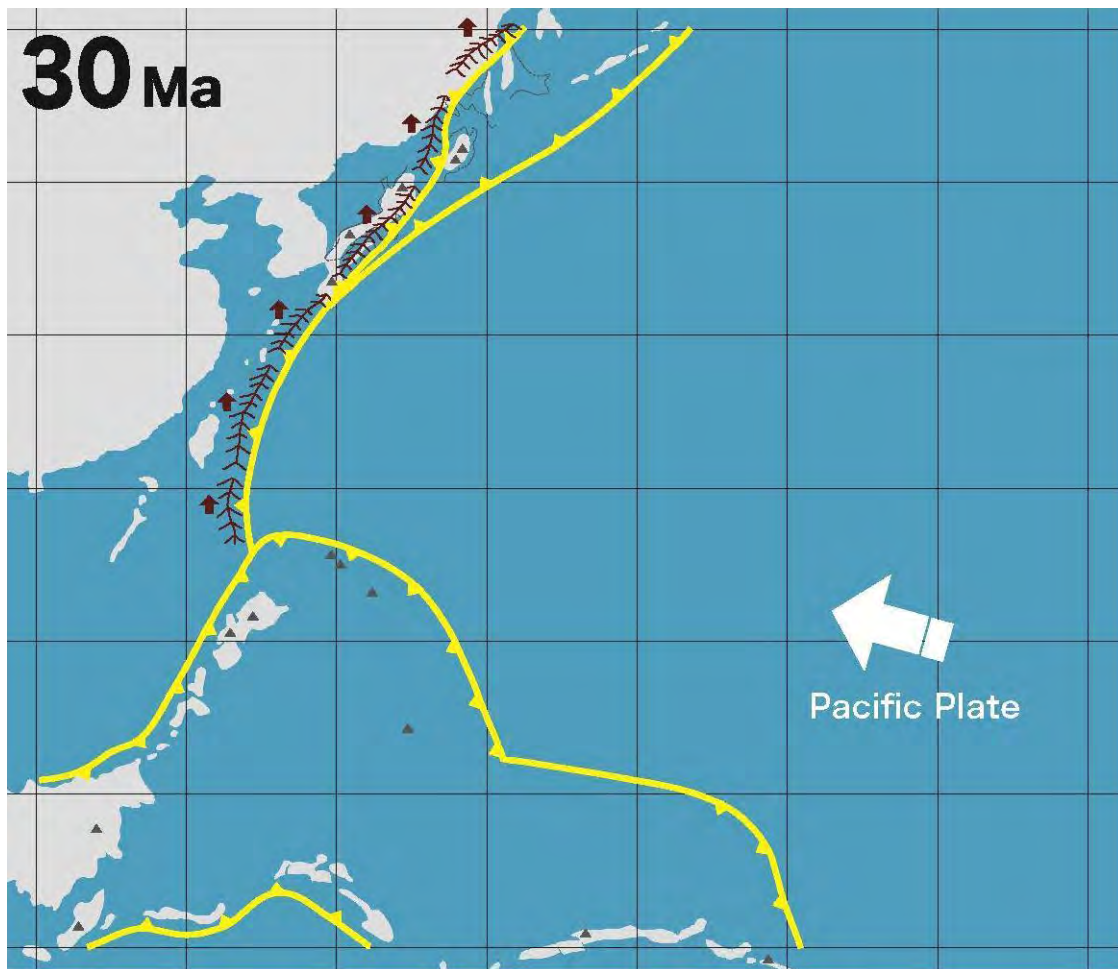
sedimentary basins throughout the Paleogene.

Divergence in the Celebes Sea became stagnant, whereas the east-west trending ridge in the proto-Philippine Sea continued to spread [4, 5].

References

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The most conspicuous Paleogene tectonic event around the northwestern Pacific margin is formation of the regional Oligocene Unconformity (Ounc; [2]). Our reconstruction regarded the event as an effect of strong compressive stress raised by closure of the marginal sea plate and subsequent collision of island arcs.

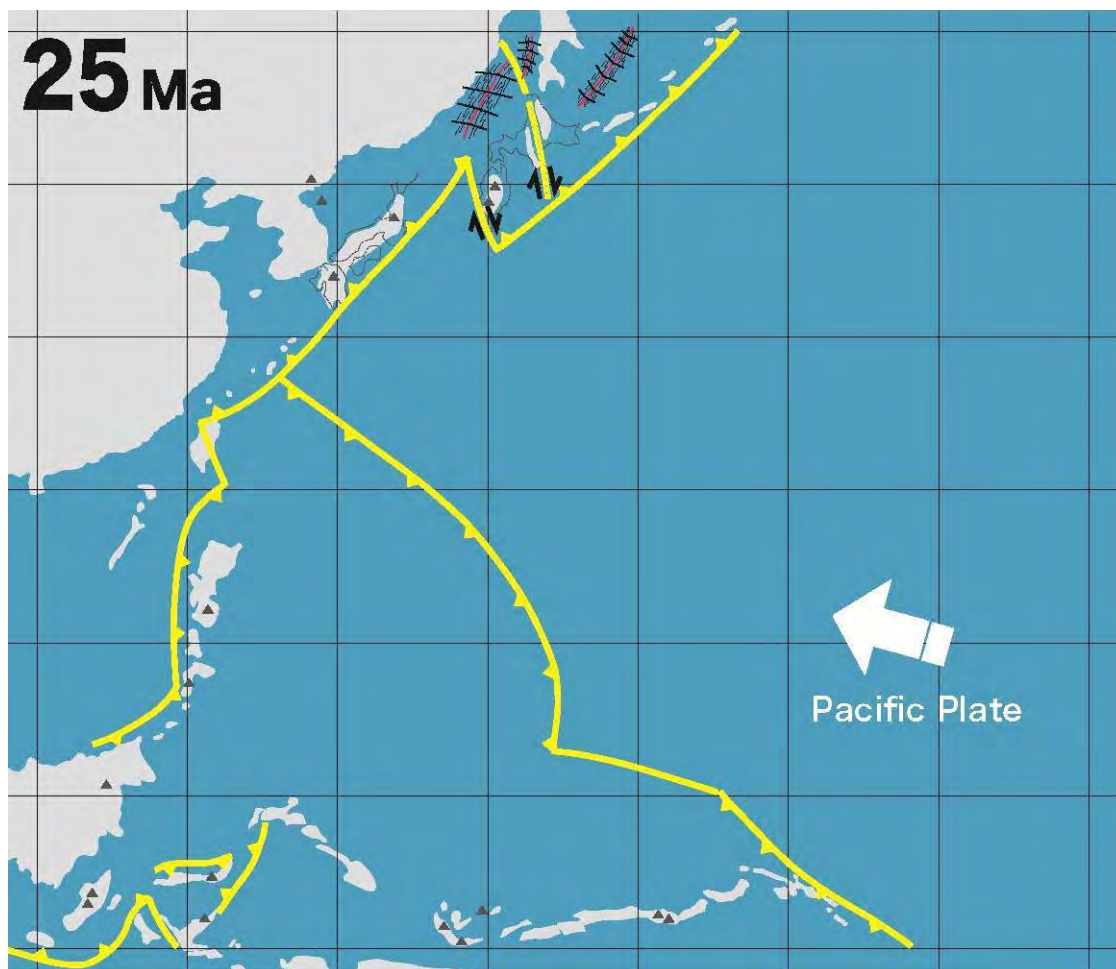
Early phase of formation of the Philippine Sea Plate had terminated. The marginal sea

was surrounded by subduction zones [3, 4].

References

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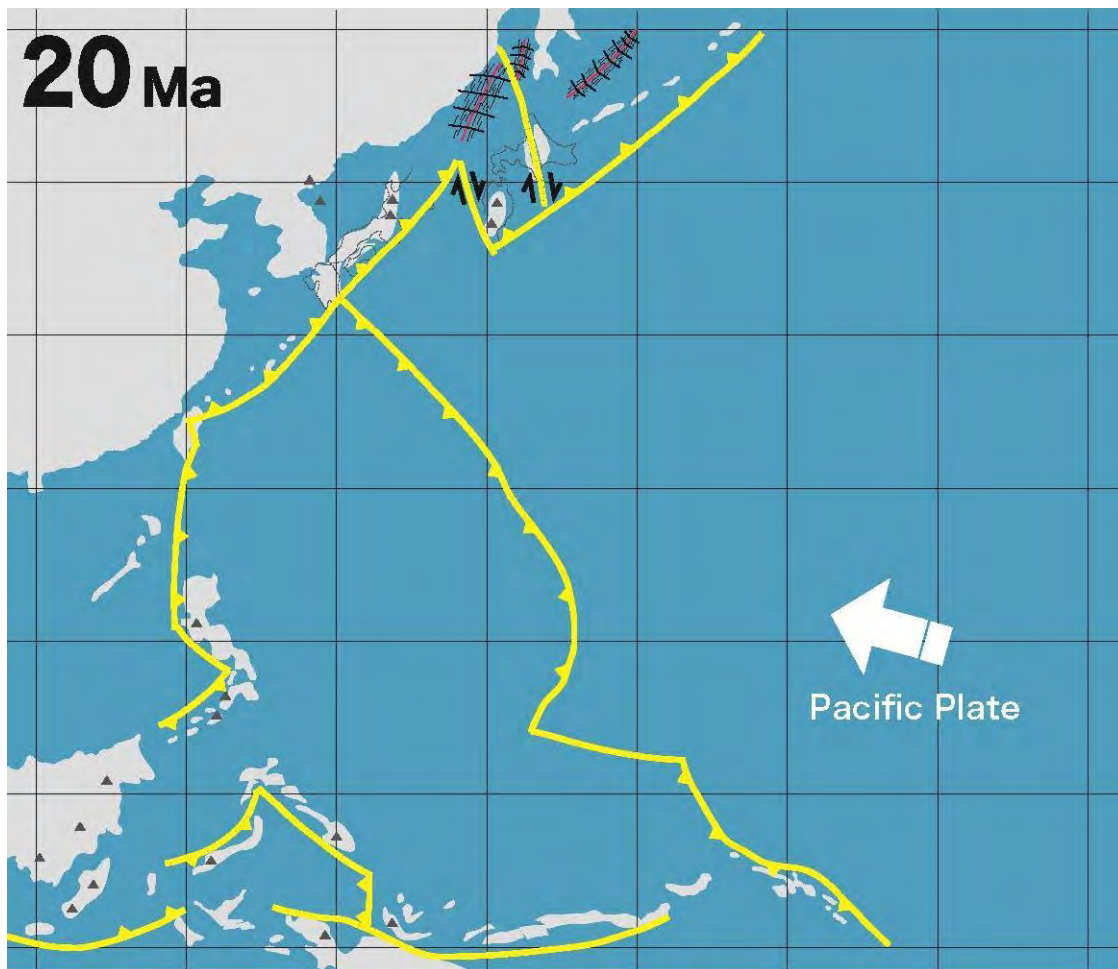
An extensive interpretation of reflection seismic data covering the offshore forearc region of northeast Japan depicted a series of transcurrent faults cutting slantwise through the arc. Based on the conspicuous trend of geomagnetic anomaly, distribution of the Paleogene arc volcanism and provenance study of the coeval detritus within forearc basins, Itoh and Tsuru [2] reconstructed the arc-arc junction, and advocated more than 200 km dextral displacement on the fault zone since the Oligocene period.

In Hall's [3, 4] reconstruction, the Philippine Sea Plate began to rotate clockwise during this period accompanied with strike-slip (sinistral) motion on the northern New Guinea. We can see an embryotic spreading center along the northeastern margin of the plate.

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As expressed by the famous bight between the Emperor Sea Mount Chain and the Hawaiian Islands, the Pacific Plate shifted its motion counterclockwise around 45~40 Ma. Since then, the Pacific Plate has been steadily moving westward, of which linear velocity in each epoch was calibrated based on data tables (p. 38~41 of [1]).

In addition to prevailing dextral motion on an arc-bisecting fault zone, numerical modeling by Kusumoto and others [2] clarified that an emergence of east-west compression and reverse fault motion is inevitable to restore configuration of the elongate basin of the Kawabata Formation in central Hokkaido, which may be linked to initiation of collision between the Kurile and northeast Japan arcs.

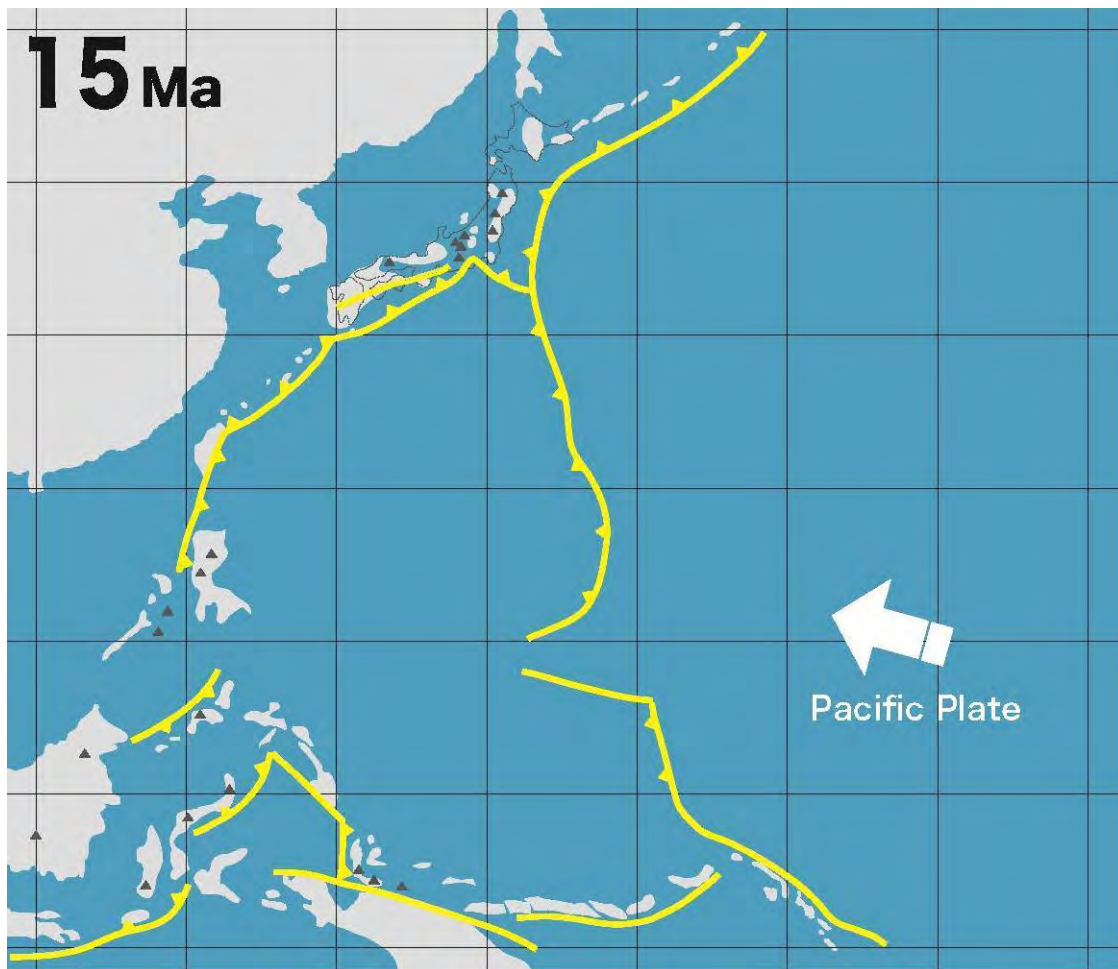
The Philippine Sea Plate continued to rotate clockwise and the Shikoku basin had been widening [3, 4].

In Hall's [3, 4] reconstruction, the Philippine Sea Plate began to rotate clockwise around the beginning of the Miocene (24 Ma) accompanied with strike-slip (sinistral) motion in northern New Guinea. We can see an embryotic spreading center along the northeastern margin of the plate. It seems, however, that many ambiguous points remain with regard to the kinematic model of the rotation event. Recently, Kimura et al. [5] advocated that the Philippine Sea Plate swiftly rotated clockwise nearly simultaneous with the clockwise motion of southwest Japan driven by the Miocene backarc opening of the Japan Sea. On the other hand, Yamazaki et al. [6] stated that the main rotation phase of the Philippine Sea Plate took place before 25 Ma based on newly obtained paleomagnetic data from the northwestern part of the plate. The authors refrain from giving final judgment on such a chaotic condition because further investigation based on firm geochronological information is needed.

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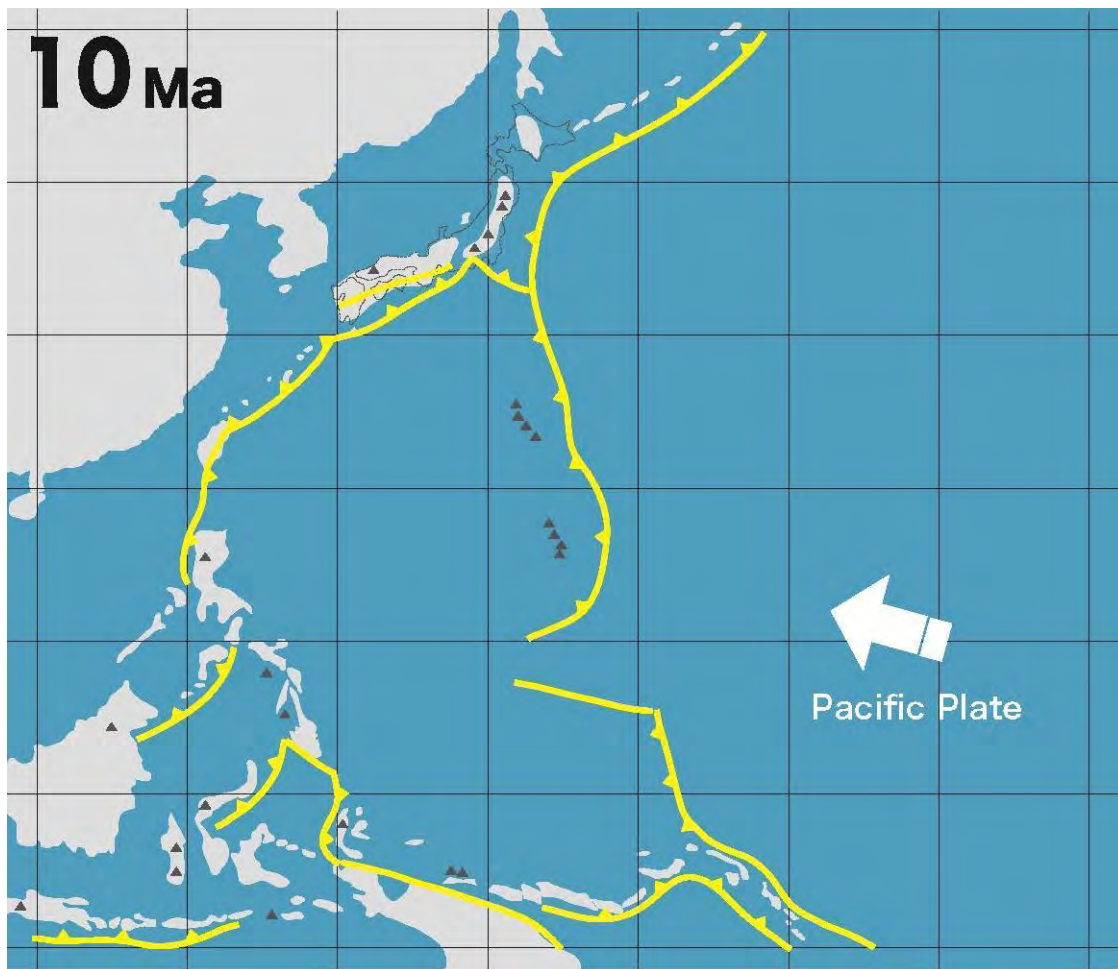
Clockwise rotation of the Philippine Sea Plate and spreading of the Shikoku basin was about to terminate. To the west of our mapped area, the Java Trench subduction zone began to roll back causing extension of the Sundaland margin [3, 4].

Although some ambiguous points remain, it has been confirmed that the rifting and backarc opening in the Japan Sea occurred in a relatively short period not later than 15 Ma through paleomagnetic studies by Otofujii and his colleagues [5]. Spatiotemporal distribution of marine sediments on the Japanese backarc support their working hypothesis. A paleomagnetic study in the eastern part of southwest Japan revealed that an arc bending had occurred successive to the backarc opening of the Japan Sea. Based on a reconstruction of terrane arrangement, Itoh [6] argued that the collision of paleo-Izu arc had raised the bending event, which is a significant constraint on coeval position of eastern margin of the Philippine Sea Plate.

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Geological evidence in the South Fossa Magna tectonic zone suggests multiple collision of landmasses on the Izu-Bonin arc, namely, Kushigatayama, Misaka, Tanzawa and the present Izu Peninsula [2]. It seems that the eastern margin of the Philippine Sea Plate has been anchored in front of the easternmost part of southwest Japan.

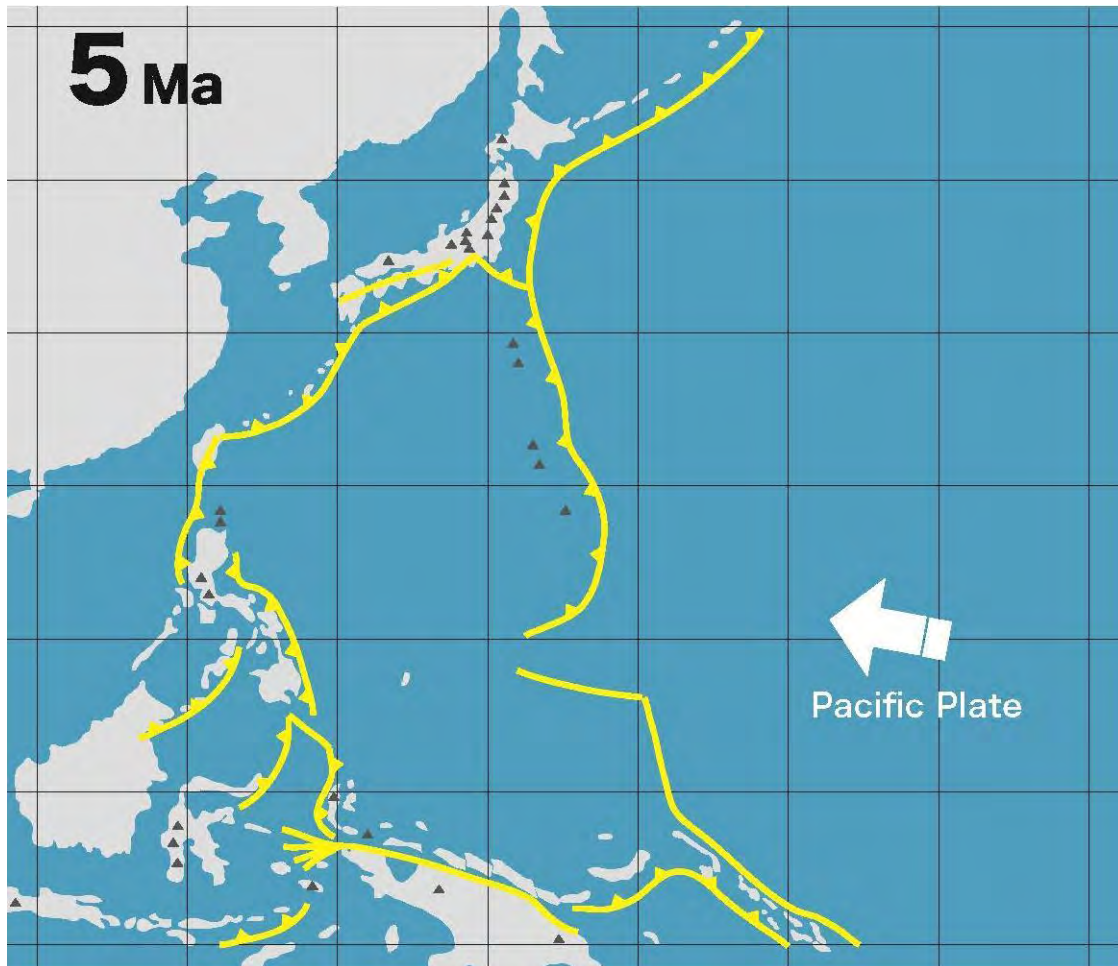
Within the Philippine Sea Plate, extension of the Sula Spur was still active to form the

North Banda Sea [3, 4].

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In Hall's model [3, 4], the South Banda Sea was under formation. The Molucca Sea

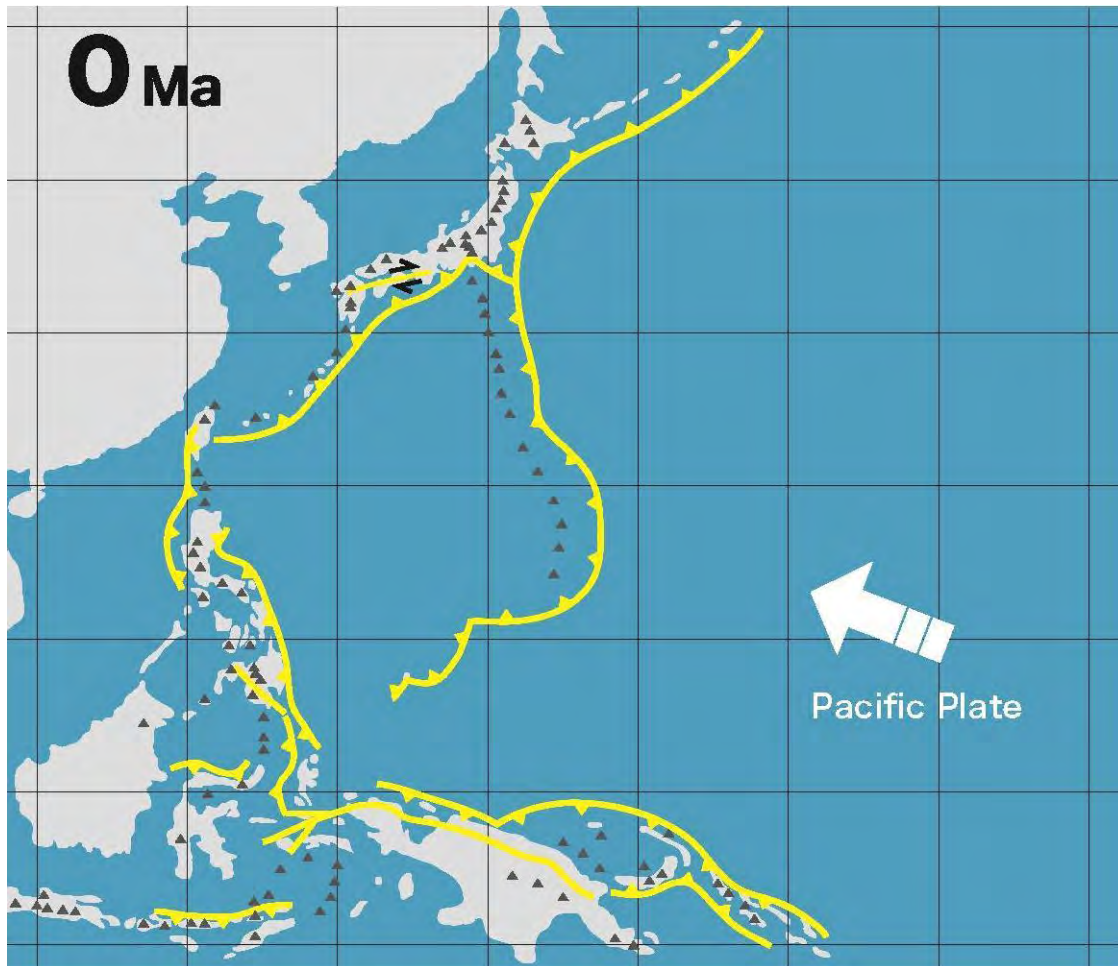
subduction was almost complete and the Halmahera and Sangihe arcs were about to collide. We can see a precursor of rifting on the Mariana arc.

Marine geologic survey and geomagnetic anomaly modeling revealed a rifting event in the Okinawa Trough since the end of Pliocene [5]. Our model incorporates its configuration. The most remarkable event in this period around southwest Japan is a strong contraction on its backarc side and formation of a regional unconformity. Itoh and Nagasaki [6] clarified that an east-west folded zone on land continues on the whole backarc shelf based on reflection seismic interpretation. Although the driving force of the tectonic episode has not been fully elucidated, some argue that revitalized subduction of the Philippine Sea Plate is responsible for the regional arc shortening. If this is the case, motion history of the oceanic plate should be reexamined in the light of deformation trend on the convergent margin.

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Based on submarine geomorphology and geology around collision front of the Izu Peninsula, Nakamura and others [2] advocated that a counterclockwise shift of converging direction of the Philippine Sea Plate occurred around 2~1 Ma. Their finding has a great significance in the field of active tectonics because west-northwestward motion of the oceanic plate enhanced right-lateral slips on the arc-bisecting Median Tectonic Line and development of intra-arc basins controlled by activities on numerous

secondary faults in southwest Japan.

Spreading on the Mariana arc has continued and the basin floor is widening [3, 4].

Temporal change in the motion of the Philippine Sea Plate [2] caused extensive wrench deformation of southwest Japan. Based on integrated analysis of seismic data, geological and geomorphological evidences, Itoh and others [5] clarified that the island arc is a continental sliver put between regional transcurrent faults with active dextral slips.

Closer look on the spatiotemporal deformation trends on southwest Japan shows a complex pattern of contraction and extension features, which are comprehensively understood as the effect of transient converging azimuth and migration of the Euler pole of the Philippine Sea Plate by Itoh [6]. Further investigation of tectonic episodes on the circum-Pacific convergent margin will pave a new way for the understanding of the plate reconstruction.

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