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Origin of the East Sea (Japan Sea) and Plate Tectonics

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東海의 起源과 板構造論

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Abstract: The origin of the East Sea is discussed in the light of modern geophysical theories such as plate tectonics and sea-floor spreading. The origin of the East Sea was due to the tensional force of the back-arc spreading which was initiated as early as late Cretaceous time or Paleocene. The spreading was asymmetric with a fast movement of eastward or southeastward and a slow westward motions. The spreading, however, was confined to the East Sea due to the change of the Pacific Plate north-northwest to west-northwest during Eocene time.

Further intensifying research based on more accurate seismic data as well as on geophysical and geological informations should be carried out continuously to understand if the spreading of the Japan Sea died out due to triple junction formed by meeting of the Pacific, the Eurasian, and the Philippine plates since the Quaternary.

要約: 東海(Japan Sea)의 起源에 관해서 板構造論(Plate tectonics)과 海抵擴張說(Sea-floor spreading)과 같은 現代地球物理學 理論이 최근에 많이 논의 되고 있다. 동해의 기원은 後期白堊紀 혹은 Paleocene 시대만큼 일찌기 거슬러 올라가서 일어난 Back-arc spreading의 장력에 기인되었다고 본다. 이 해저확장의 시작은 동쪽 혹은 남동쪽으로 빠른 운동을 하였지만 서쪽으로는 느린운동을 하게 되어서 非對稱性 확장을 이루게 되었다. 그러나 Eocene 동안 北北西에서 西北西로 이동하게된 태평양판의 새로운 운동방향의 변화와 Philippine 판의 생성 때문에 동해의 확장은 오늘날의 일본 열도에 제한되어 멈추게 되었다고 본다.

第四紀 以後 동해의 확장은 소멸되고, 太平洋板, Philippine板 및 Eurasia板의 서로 만남으로 하나의 Triple junction을 형성하여 힘의 평형을 이루고 있는지에 대해서는 충분한 地球物理學, 地質學的 자료는 물론 地震資料의 더욱 정밀한 분석에 기초를 둔 연구가 수행됨으로 풀릴 것이다.

INTRODUCTION

Many geophysical researchers have proposed various hypotheses about the origin of the East Sea. So far there are no definite theories on the formation of the East Sea. Especially geologists and geophysicists of Korea, Japan, and Russia have been interested in the origin of the East Sea because its clue is very relevant to the global tectonics of the Far East.

Three plates meet each other near the Japan Island Arc (near Sagami Bay?). The Pacific Plate penetrates deeply under the Eurasian and the Philippine plates, while the Philippine Plate penetrates to the Eurasian Plate. Characteristic evidence of subduction includes a trench, the Benioff zone, dipping beneath the island arc, volcanism in the island arc and folded sediments in the trench. Subduction of the Pacific plate lithosphere is apparently the result of sea-floor spreading. However it is not the end product. Karig (1971) demonstrated that there is evidence of spreading on the con-

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cave side of (or behind) island arc and that this spreading may be the tectonic process which has formed the marginal seas. Uyeda (1980) suggested that the formation of marginal seas of the Western Pacific is directly related to the subduction of the Pacific Ocean crust beneath the island arc and therefore related to the oceanic sea-floor spreading process. Honda and Masatsuka (1952) studied the mechanism of the earthquakes and the stresses in the East Sea and found that the directions of maximum horizontal pressure axes of deep and intermediate earthquakes are perpendicular to the deep and intermediate earthquake zones, respectively. Uyeda and Ben-Avraham (1972) also studied heat flow in the eastern Asia and western Pacific region and found the high heat flow in the East Sea. He also found NE-SW magnetic lineation in the East Sea without locating the center of spreading. This indicates that there must be several spreading centers and the spreading is also asymmetric with a very slow rate of spreading westward (Hilde and Wageman, 1973). The main attempt of this paper is to present when and how the East Sea was formed and why the opening of the East Sea is no longer active in the light of the global tectonics of the Far East.

GEOPHYSICAL STUDIES OF THE EAST SEA

The East Sea has an oceanic crust covered by a layer of sediments less than 2 km thick (Andreyeva and Udincsev, 1958; Murauchi, 1966) and shows uniformly high heat flow (Figs. 1 and 2). Yasui et al. (1968) found that heat flow of the average of 155 measurements is $2.22 \pm 0.53\ \mu\ cal/cm^2$. sec in the East Sea. They also indicated that heat flow is very high in the northeastern basin and the westernmost plateau, while an east-west zone crossing Yamato rise has relatively low heat flow. This

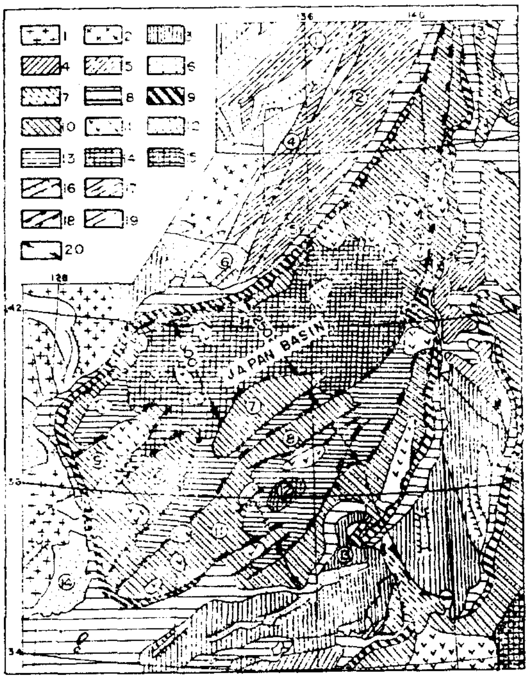

Fig. 1. The geological structure of the East Sea and its vicinity (Bersenev, 1972)

a) Number of the legend
1 Pre-Cambrian continental crust
2 Khonkay Central Massif
3 Paleozoic Folding System
4-5 Mesozoic Folding System
4 Anticlinorium 5 Synclinorium
6 Paleozoic and Mesozic depression
7 Late-Cretaceous and Cenozoic sag
8 Continental shelf
9 Continental slope and island slope
10 Base of the continent and the island
11 Volcanic submarine hill
12 Other submarine hill
13 Depression 14 Deep Sea Basin
15 Deep Sea Trough
16 Overthrust and reverse fault
17 Displacement with the direction
18 Expansion 19 Other fault
20 Assumed direction of expansion of the earth's crust and its size in Km.

b) Numbers in the map
1 Amur-Ussuri Synclinorium
2 Main Sichote-Alin Synclinorium
3 West Sakahalin Synclinorium
4 Main Sichote-Alin Anticlinorium
5 Coast Anticlinorium
6 South Sichote-Alin Folding
7 Yamato North Ridge
8 Yamato South Ridge
9 Korea Plateau 12 Honshu Basin
10 Ulleung-do 13 Hida Folding
11 Oki Ridge 14 Tsushima depression

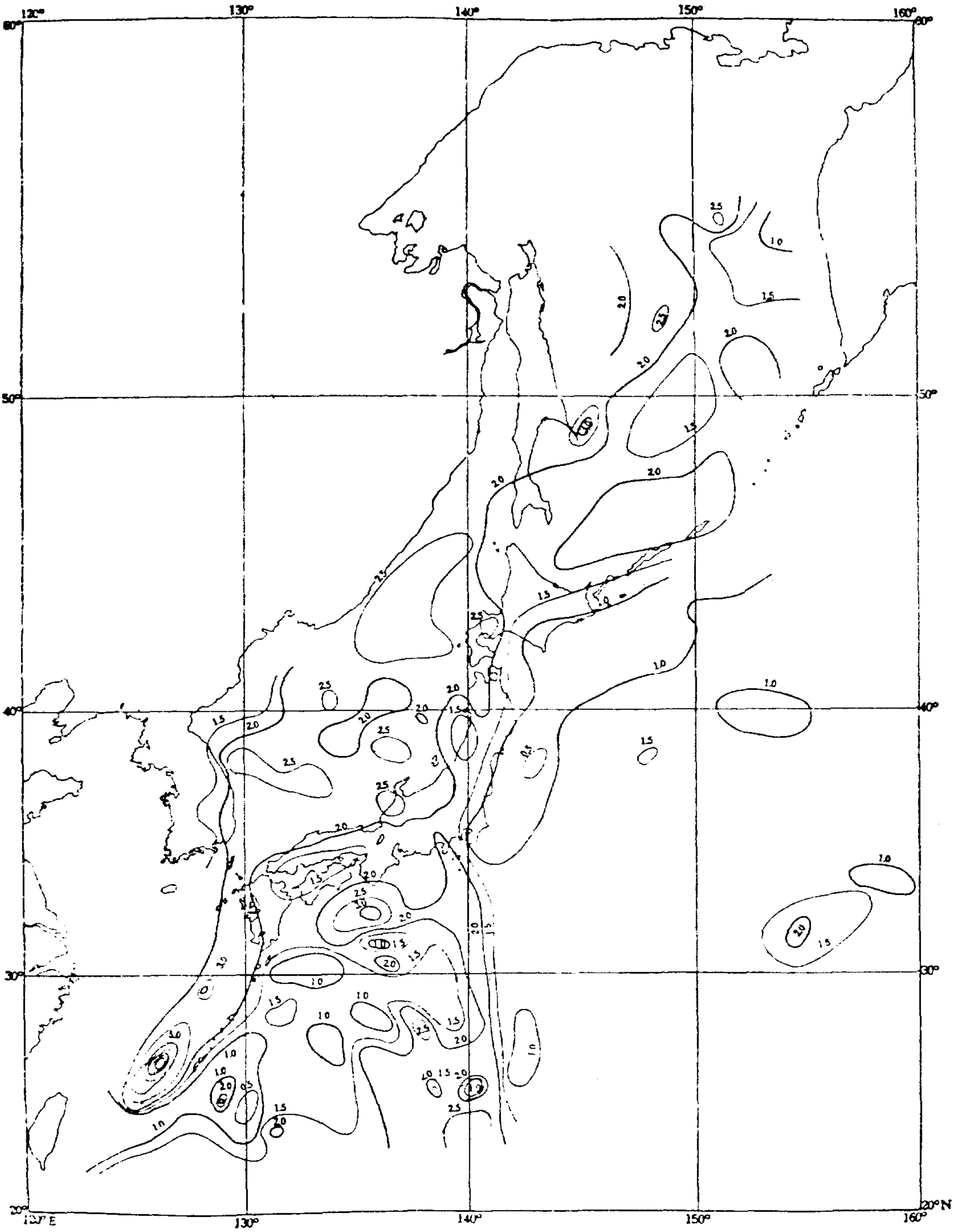

Fig. 2. Iso-heat flow map in and around Japan (Uyeda, 1972).

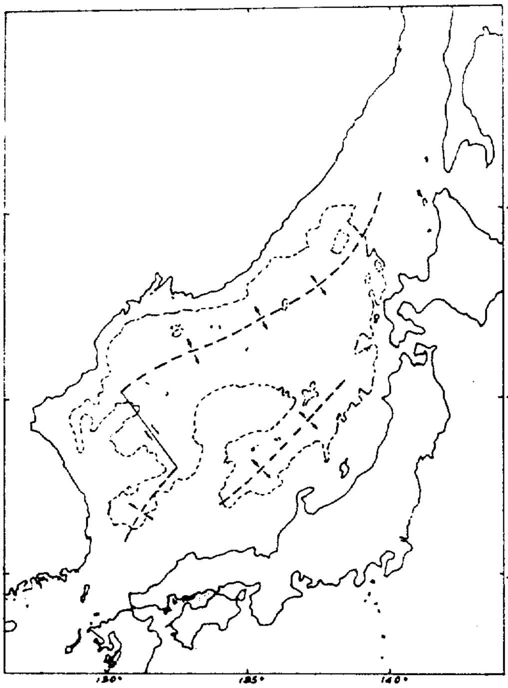

Fig. 3. Initial spreading centers occurred in the Japan and Ulleung basins. Later spreading occurred in the Yamato Basin (Hilde and Wageman, 1973).

indicates its origin by process of opening in a relatively recent geologic time(Fig. 3). A number of different mechanisms have been proposed for the opening of the East Sea and more of less similar marginal seas. Matsuda and Uyeda (1971) suggested that the magma generated along the upper surface of the descending slab rises through the upper mantle and creates the new oceanic lithosphere of marginal sea due to resultant oceanward drift of the coastal zone to form an island arc.

Sleep and Toksöz(1971) proposed that a descending slab induces a secondary hydrodynamic flow in the upper mantle that causes tensional formation of a marginal sea. Uyeda and Miyashiro (1974) stated that the Japan Sea was originated due to the subduction of the Kula Plate which induced the back-arc spreading of the tensional force, so called Mariana type, in the late Cretaceous time. Magnetic anomalies are elongated east-northeast in the Japan Sea. The lineations are much less pronounced than those in the Pacific basin, indicating that the spreading occurred at numerous microcenters and not at a single spreading center (Isezaki and Uyeda, 1973). Isezaki (1973) found out that magnetic lineations are subparallel to the trend of Honshu Island, but not quite so with the lineations in the Pacific just on the other side of the arc. He also stated that no apparent center of symmetry was noticed, although numerical elaboration indicated the existence of a spreading center in the Japan Basin. Hilde and Wageman (1973) proposed, from topographic and seismic reflection profile surveys, that the opening occurred by a spreading along two major ridges. Bersenev(1972) suggested that the opening was due to the depression and expansion of the earth's crust. The opening also influenced the geological structure of the Korean Peninsula that is located at the east of Sino-Korean Paraplatform and apart of the Mesozoic belt of the marginal tectonic domain. The Mesozoic Tectonic Belt consists of uplifting and depression trending toward NE or NNE which are formed of folds, faults, Pacific-type volcanics, and granitoid intrusions. A possible manifestation of the different stress regimes results in the different type of mineralization. Uyeda and Nishiwaki(1980) pointed out that porphyry copper-type deposits are favored by the compressive stress regime of the Chilean-type subduction zones and the massive sulphides by the tensional regime of the Mariana-type subduction. These phenomena may explain the geodynamics of the Korean Peninsula under the tensional force of the opening of the East Sea. The Chugaryong Graben stretched from Seoul to Wonsan also may be one of the spreading centers that occurred in the neighborhood of the East Sea.

The moving direction of the Pacific Plate has not been constant. The moving direction changed from NNW to WNW in Eocene (≈40 m.y. B.P.). The Kula-Pacific Ridge apparently descended beneath Japan in the late Cretaceous time. After the ridge descent, the area on the continental side of the subduction zones was probably subjected to great tension with the resultant opening of the East Sea. The Philippine Sea Plate was also formed by change of the direction of the Pacific plate.

When the direction of Pacific Plate motion changed, the Philippine Basin might not have readjusted its motion in complete harmony with the larger Pacific Plate, to that new subduction was induced at the former transform fault between Kula Pacific Ridge and Philippine Ridge (Uyeda and Ben-Avraham, 1972). Consequently the transform fault became an island arc during the Eocene. It resulted in the Philippine Sea Plate that was warmer and sparser than the Pacific Plate. One of important findings in recent studies is the clockwise rotation of the Philippine Basin and the islands of Guam and the Mariana Arc.

SEISMOLOGICAL VIEW OF THE EAST SEA

It is also important to investigate focal mechanisms of earthquakes of the East Sea and its vicinity to find the maximum pressure and tension axes. The directions of the horizontal components of the maximum pressure of the stresses producing the deep and the intermediate earthquakes are found to be normal to the deep and the intermediate earthquake zones, respectively (Honda and Masatsuka, 1952). Figure 4 shows isofocal depths of earthquakes of the East Sea. Kim (1980) studied the focal mechanisms of earthquakes and suggested that the maximum pressure axes were subject to trend on the NW-SE side. This explains the geodynamics of the underthrusting Pacific Plate be-

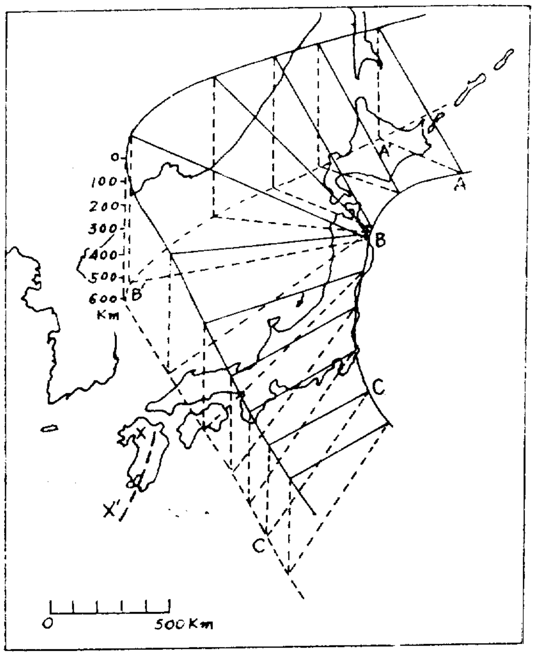

Fig. 4. Focal depth distribution of deep and intermediate—focus earthquakes in and near the East Sea (Honda and Masatsuka, 1952).

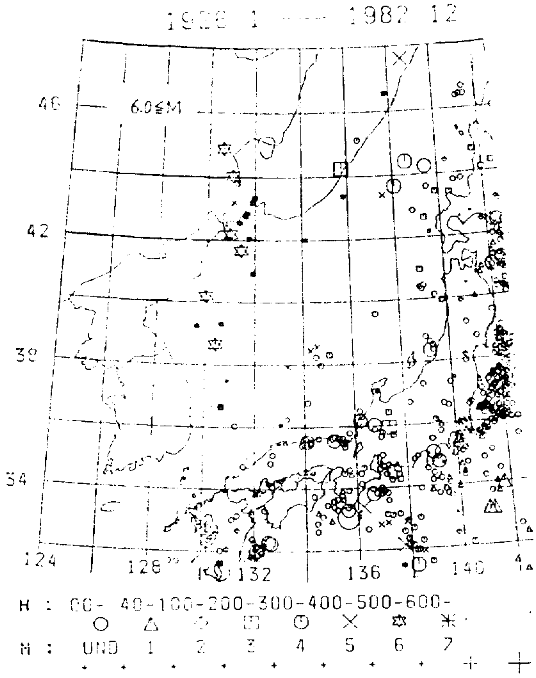

Fig. 5. Earthquakes around Japan, magnitude 6 and over for the period 1926~1982 (data presented by JMA and NOAA).

Table 1. Distribution of tsunami sources or earthquake epicenters in the Sea of Japan.

No.	Date	Lat. (°N)	Long. (°E)	M	m*
1	05-12- 701	35.7	135.4	7.0	2
2	11-02- 850	39.0	139.9	7.0	2
3	08-02- 887	37.5	138.1	6.5	2
4	11-26-1614	37.5	138.0	6.5?	2
5	08-29-1741	41.6	139.4	6.9?	3
6	10-31-1762	38.1	138.7	6.6	1
7	06-13-1792	43.5	140.6	6.9	2
8	02-08-1793	40.9	140.0	6.9	1
9	07-10-1804	39.2	139.9	7.1	1
10	09-25-1810	39.9	139.9	6.6	0
11	12-07-1833	38.9	139.2	7.4	2
12	03-14-1872	34.9	132.0	7.4	0
13	12-09-1892	37.1	136.7	6.4	0
14	03-07-1927	35.5	135.2	7.3	−1
15	05-01-1939	40.1	139.5	6.8	−1
16	08-02-1940	44.3	139.5	6.8	−1
17	11-04-1947	43.8	141.0	6.7	1
18	04-07-1964	40.8	139.0	6.9	−1
19	06-16-1964	38.5	139.2	7.5	2
20	12-11-1964	40.4	138.9	6.3	−1
21	09-06-1971	46.7	141.4	6.9	0
22	05-26-1983	40.4	138.9	7.7	3

* Size of tsunami(m) is defined (Iida, 1958) as follows:

Size (m)	visual run-up height (meters)	description
−1	less than 0.5	no damage
0	~1	damage occurs
1	~2	boats at the coast damaged
2	4-6	inland damage, some people loss
3	10-20	more than 400km greatly damaged along the the coastal areas
4	more than 30	more than 500km greatly damaged along the coastal areas

neath the Eurasian Plate in the surroundings of the Japan Trench.

The positions of the volcanoes ever erupted in the historical time and the trend of the active volcanoes are coincident with the intermediate earthquake zone. There are no deep-focus earthquakes below 700km in the deep-focus earthquake zone. The maximum penetration of the rigid lithosphere is likely to act as the plastic flow rather than the brittle character below 700km.

Although most earthquakes in the East Sea are found to be deep-focus earthquakes, there are some shallow-focus earthquakes which often generate tsunamis near the Japanese Islands (Fig. 5). As shown on Fig. 6 and Table 1, 22 tsunami sources are presented for the period 684-1983. These tsunamis often gave considerable damage to the east coast of the Korean Peninsula as well as the western part of the Japanese Islands. Furthermore, the tsunami warning system in the East Sea has not been operated so far. As a result, the recent Akita Earthquake of May 26, 1983 resulted in 3

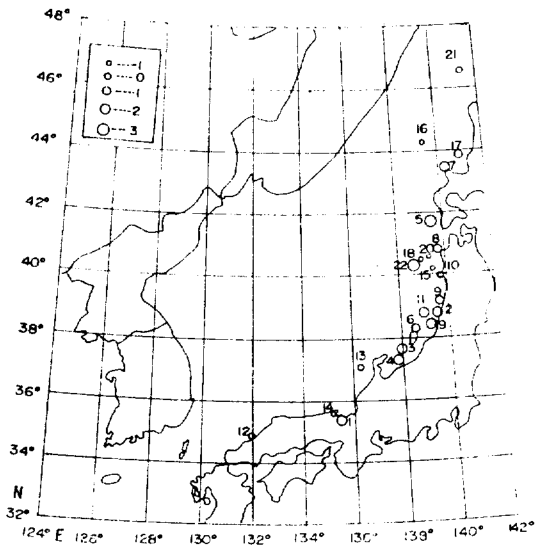

Fig. 6. Distribution of tsunami sources(or epicenters) in the East Sea (684 A.D.—1983).

deaths and a great loss of properties in the east coast of Korea. It is adviserable to operate the systematic network of seismograph stations in the Korean Peninsula to forecast arrivals of tsunamis in the east-coast of Korea since most heavy industrial plants and some critical facilities (nuclear power plants) are located along the eastcoast of Korea.

THE TECTONICS OF THE EAST SEA

In order to study the global tectoincs of the Far East, it is of importance to discuss on the origin of the Philippine Sea as well as the East Sea. The Philippine Sea must have been formed after the creation of the East Sea. About 100 m.y. B.P., Kula Pacific Ridge moved toward north-northwest with Kula Plate and descended beneath Japan 80 to 90 m.y. ago. At that time the East Sea began to open. About 40 m.y. ago, the direction of motion of the Pacific plate changed to west-northwest and the transform fault became a subduction zone. At the same time, the tensional force applied to the opening of the East Sea became to decrease. The Philippine Sea Plate and the Izu-Mariana Arc were formed at the time of the subduction of the Pacific Plate.

Uyeda (1981) suggested two types of subduction. (Fig. 7) One is the back-arc spreading with tension and regional high heat flow (called Mariana type), and the other is the continental arc with compression and no regional high heat flow. Further south beneath the Mariana islands the earthquake zone becomes vertical. On the other hand, the intermediate earthquake zone of the Philippine Sea Plate is planar and dips at 45°. This difference between the eastern and western branch of the Philippine Sea Plate is probably caused by the rotation of the Paific Plate beneath the Philippine Sea Plate. The physical motion of the Pacific Plate is translational and rotational with respect to the Eurasian and Philippine plates. Toksöz (1975) studied models of the Pacific Plate subducting beneath the Eurasian Plate and beneath the Philippine Plate and found that descending rates are 7.5 cm/year with complete slab motion in the Eurasian Plate and 1.2 cm/year with bent slab motion in the Philippine Plate, respectively, whereas the descending rate of the Philippine Plate beneath the Eurasian Plate is 6.7 cm/year with weak or broken slab motion.

DISCUSSION AND CONCLUSION

As we disscussed on the origin of the East Sea, so far there are no definite explanations on the origin except for opinions that the East Sea was originated from the opening of the earth's crust. The author is not against the back-arc spreading hypothesis that Uyeda and Miyashiro (1974) suggested. It explains the tensional force in the marginal sea and several micro-spreading centers. The geomorphological and geophysical observations of the Korean Penensula, eapecially the Chugaryong Graben, geological structure, and mountain ranges are

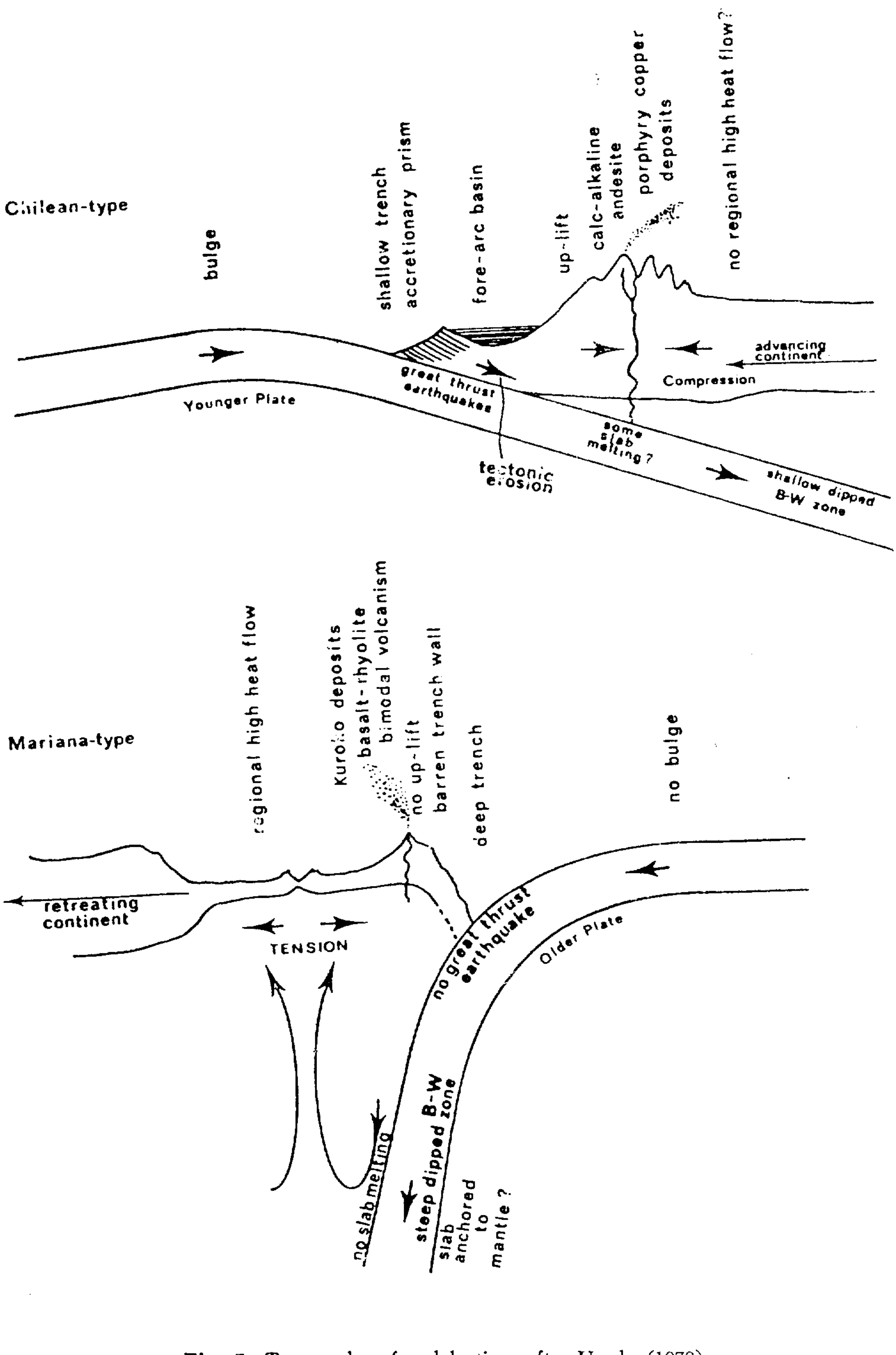

Fig. 7. Two modes of subduction, after Uyeda (1979).

coincident with the back-arc spreading of the East Sea. This back-arc spreading decreased in the middle of Cenozoic time when the Kula-Pacific Ridge descended beneath the Eurasian continent and the Kula Plate disappeared. At the same time the direction of the Pacific Plate was changed NNW to WNW, and a triple junction may be formed at and near the East Sea and the spreading motion of the East Sea may die out owing to equilibrium of the driving forces of three plates.

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