静岡大学地球科学研究報告 23 (1996年7月) 1頁～8頁
Geosci. Repts. Shizuoka Univ., 23 (July, 1996), 1-8

The trench-trench-trench type triple junction and tectonic evolution of Japan

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Abstract The topography around the trench-trench-trench triple junction off the Kanto Plain and Neogene tectonic evolution of the Japanese Island Arcs have been examined. The most important factors for the tectonics are the deformations of the subductive boundary around the triple junction for retention of the minimum curvature of subduction of the thick Pacific Plate along an irregular boundary with an uncinate process, created by the retreat of the Izu Trench on the Philippine Sea Plate. The Great Bend of the zonal structure in central Japan, the east-west compressional stress field in the Southwest Japan, and the tectonic evolution of northeast Honshu can be systematically explained with the deformations.

Key words: triple junction, plate tectonics, Neogene tectonics of Japan, bending of zonal structure, minimum curvature, Pacific Small Circle, Mogami Small Circle

INTRODUCTION

The trench-trench-trench type triple junction off the Kanto Plain is a unique point on the present global tectonic framework (Fig. 1), yet the tectonic evolution around the triple junction is important for understanding the mechanisms behind tectonic processes in mobile belts.

Since the initial stages of plate tectonic theory, mystery has surrounded the virtually stable position of the triple junction, in light of the potential variation in plate motions. Another mystery has been the processes responsible for large scale bending in the zonal structure of central Japan, first recognized more than 100 years ago (NAUMANN 1887). Recent studies of the Neogene tectonics of central Japan make clear that the two mysteries are manifestations of the processes at the face and back of the triple junction off the Kanto Plain.

PLATE TECTONIC FRAMEWORK

The triple junction off the Kanto Plain is related to the motions of the Pacific, Philippine Sea, Eurasian and North American Plates (Fig. 1 and Table 1). The Philippine Sea Plate is subducting northwestward under the North American Plate along the Sagami Trough and under the Eurasian Plate along the Suruga Trough, Nankai Trough and Ryukyu Trench. The Pacific Plate descends beneath the Philippine Sea Plate along the Izu-Bonin Trench. The Pacific Plate subducts under the North American Plate along the Japan Trench, and the Eurasian Plate subducts under the North American Plate along the eastern margin of the Japan Sea.

MCKENZIE & MORGAN (1969) examined the behaviors of plate positions around various types of triple junctions, determining that the position of trench-trench-trench type triple junctions are not stable with respect to plate motions. According to their analysis, the position of the triple junction should move along the Sagami Trough, caused by the motion of the Philippine Sea Plate (Fig. 2a).

The descending slab of the subducting Philippine Sea Plate can be recognized along the Nankai Trough and Ryukyu Trench in the Wadati-Benioff Seismic Zone. Assuming the present rate of plate motion, the subduction of the Philippine Sea Plate has continued for 7 m.y., based on the slab length (ISHIBASHI & ISHIDA 1989; ISHIDA 1992). The age

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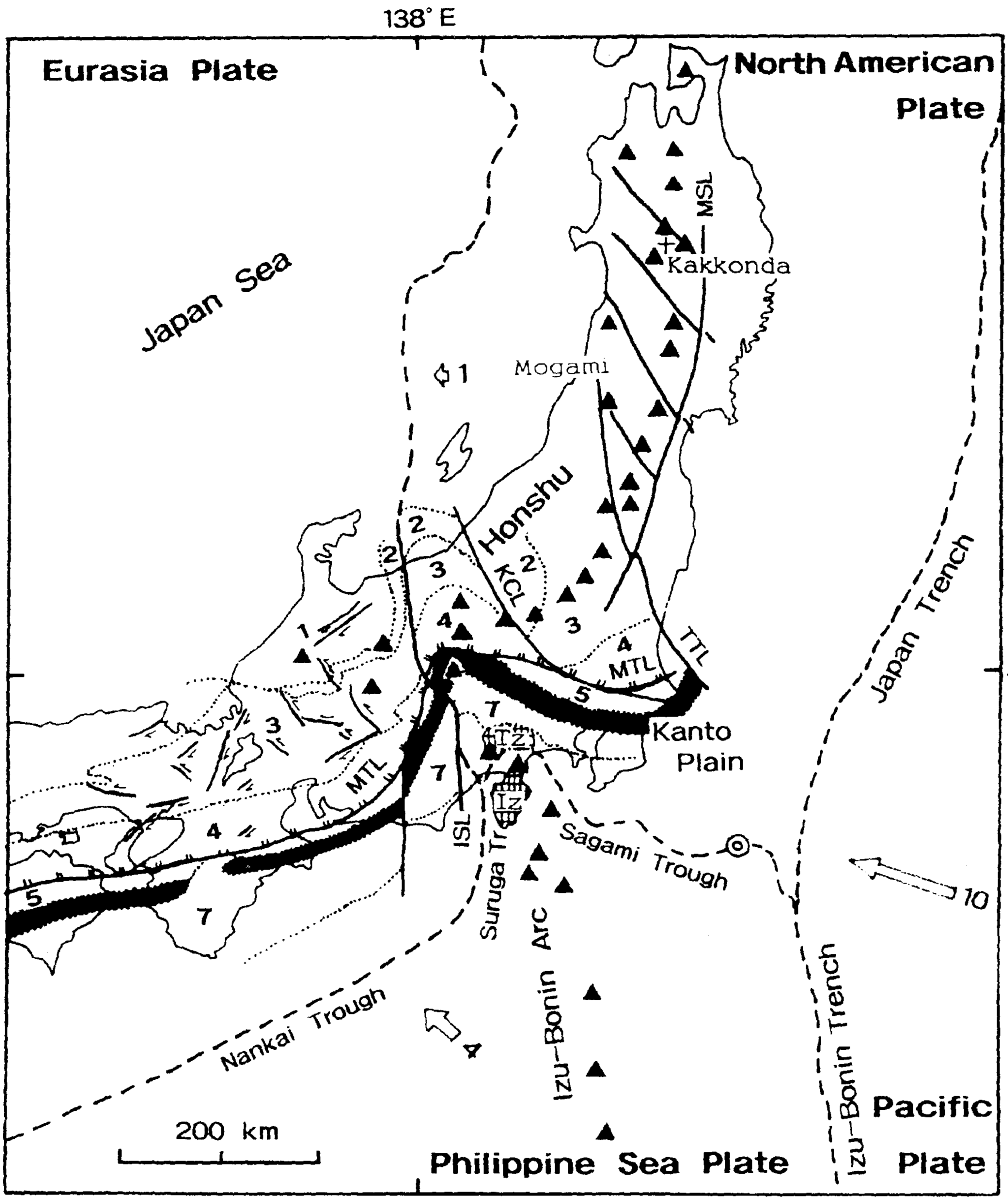
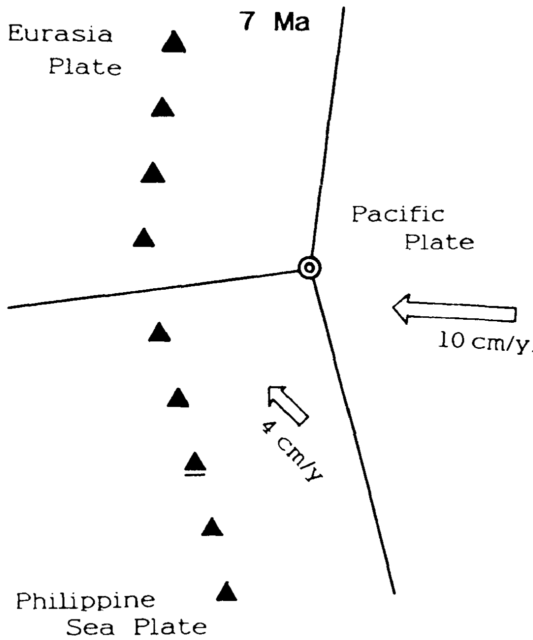


Fig. 1 Plate Tectonic framework of the triple junction and the Philippine Sea Plate. Double circle: trench-trench-trench type triple junction, white arrows: present plate motions in cm/year relative to the Eurasian Plate, arrow length represents the motion for 1 m.y., black triangles: active volcanoes, dotted lines: boundaries of accretionary belts, solid lines: faults, thin arrows: strike slip motion of active faults (Research Group for active faults of Japan, 1994), MTL: Median Tectonic Line (with double tick marks), ISL: Itoigawa-Shizuoka Tectonic Line, KCL: Kashiwazaki-Choshi Tectonic Line, TTL: Tanakura Tectonic Line, MSL: Morioka-Shirakawa Tectonic Line, Tz: Tanzawa Block, Iz: Izu Block, 1: Hida Belt, 2: Hida Marginal-Joetsu Belt, 3: Mino-Tamba-Ashio Belt, 4: Ryoke Belt, 5: Sambagawa Belt, 6: Chichibu and Sambosan Belt (black), and 7: Shimanto Belt.

of 7 Ma is consistent with the start of the accretion, collision and formation of the forearc basin along the northern margin of the Philippine Sea Plate (Niitsuma & Akiba 1985).

A volcanic front appears on the slab at a slab depth of 100-150 km (Tatsumi 1989) along the subducting boundary of the Pacific Plate, i.e., along the Japan Trench and the Izu Trench, and crosses the zonal structure (Fig. 1). If the position of the triple junction were moved, the crossing point on the zonal structure should be also moved and a wide volcanic zone should be distributed on the Kanto Plain. However, no evidence of such a wide volcanic zone exists (Fig. 3).

The volcanic arc on the Philippine Sea Plate, the Izu-Bonin Arc, might collide with the Honshu Arc, because of the buoyant nature of the volcanic arc. Anomalously thick crust more than 40 km thick and



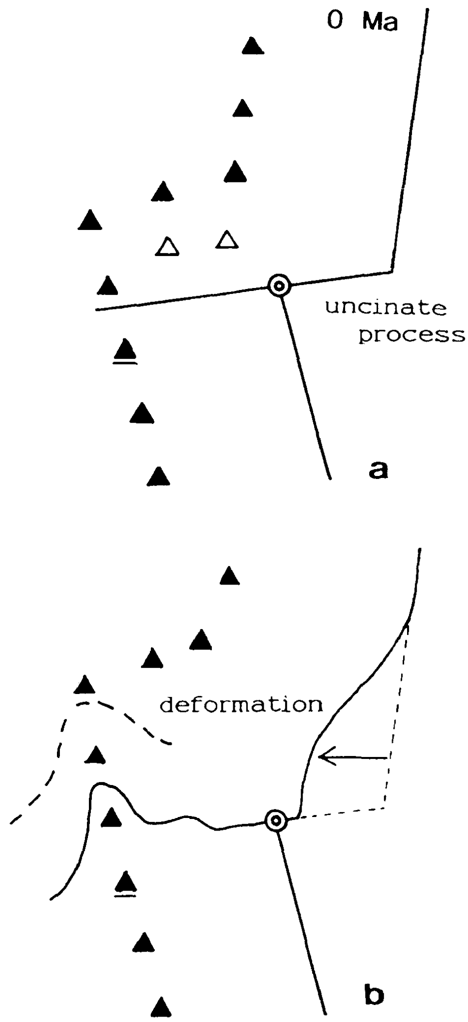


Fig. 2 Evolution of the plate boundary caused by the motion of the Philippine Sea Plate. Double circle: triple junction, solid triangles: active volcanoes, open triangles: dead volcanoes.
a. Non-deformational case: original position of the triple junction remains at the tip of an uncinate process at which the Pacific Plate subducts.
b. Deformational case: apparently stationary position of the triple junction for the subductive plate is realized by plate deformation, caused by the depression of the uncinate process. Arrow: plate deformation, dotted line: original shape, broken line: Great Bend of the zonal structure.

low P wave velocities in the upper mantle, which are observed north of the colliding boundary (FURUMOTO *et al.* 1989), should be related with the collision (NIITSUMA 1989).

GEOMETRIC CHARACTER OF THE TRIPLE JUNCTION

Both the Philippine Sea Plate and Pacific Plate subduct under the Eurasian Plate and the North American Plate to the southwest of the triple junction. The double subduction might be traced to the triple junction, where the North American Plate is underlapped by the Philippine Sea Plate and Pacific Plate. However, the North American Plate is underlapped directly by the Pacific Plate to the northeast of the triple junction (Fig. 3). Because the eastern margin of the Philippine Sea Plate has a certain thickness, a triangle-shaped hole can be estimated to occur at the triple junction, and this hole should continue into the asthenosphere.

The deepest parts of the triple junction can be found along the axis of the Japan Trench to the Izu Trench. However an irregular topography is observed west of the axis, which is characterized by a large scale collapse (Fig. 3). The western margin of the collapse topography can be bounded by a straight line continuing smoothly to the Izu-Bonin Trench. The Katsuura Basin is located on the northwestern margin of the collapse topography, and the east of the basin is also characterized by a large scale southward collapse. The topography around the triple junction supports the existence of the hypothesized hole, which has been filled up with the collapsed materials from the plate boundary and

Table 1 The Euler poles and rotation rates for the trench-trench-trench type triple junction off the Boso Peninsula, based on SENO (1993). PA: Pacific, PH: Philippine Sea, Eu: Eurasian, and NA: North American Plates.

Plate Pair	Euler Pole		Rotation Rate
	Lat.(° N)	Lon.(° E)	° /m.y.
PA-PH	1.24	134.19	1.000
EU-PH	48.23	156.97	1.085
NA-PH	44.19	160.34	0.875
PA-EU	61.07	-85.82	0.900
EU-NA	62.61	136.04	0.244
NA-PA	48.71	-78.17	0.783

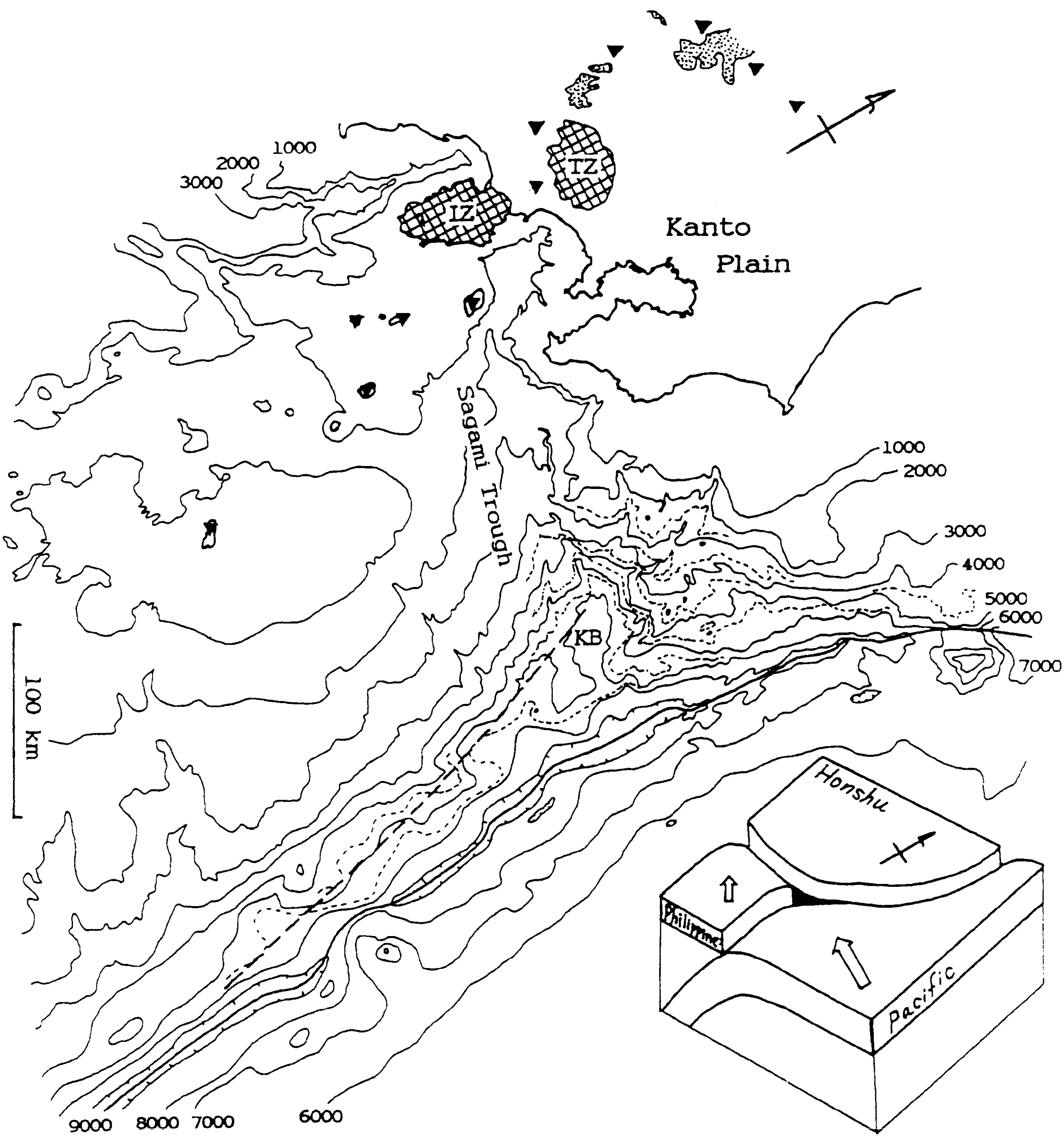


Fig. 3 Collapse topography around the triple junction (Hydrographic Department of Japan, 1991), and block diagram of subducting plates and triangular hole at the triple junction. Depth contours: in meters, solid line: trace of the deepest part along the Japan Trench and Izu-Bonin Trench, broken line: western margin of collapse topography, triangles: active volcanoes, dotted area: late Miocene to Pleistocene volcanics (Geological Survey of Japan 1992), TZ: Tanzawa Block, IZ: Izu Block, KB: Katsuura Basin, and white arrows: plate motions.

turbidites from the Honshu through the Sagami Trough. The real position of the triple junction can be determined to be north of the Katsuura Basin.

DEFORMATION AROUND THE TRIPLE JUNCTION

If the Eurasian and North American Plates located north of the troughs were not deformed, the position of the triple junction would move along the Sagami Trough, as mentioned above (Fig. 2a). However, large scale deformation is taking place in central Japan, and the zonal structure has been bent (Fig. 1). The trough chain resulting from the subduction of the Philippine Sea Plate is also bent parallel to the zonal structure (Fig. 2b). Southwest Japan is situated under an east-west compressional stress field and movement along coupled strike slip faults are releasing the stress, such as the Hanshin-Awaji Earthquake of 1995 January (Fig. 1).

If the position of the triple junction were able to move and the Eurasian and North American Plates were deformed in association with the motion of the Philippine Sea Plate, the position of the triple junction might appear stationary relative to the eastern margin of the North American Plate, and the volcanic arc might nearly cross the initial position on the North American Plate boundary (Fig. 2b). The evidence of deformation in central and southwest Japan supports the idea that a balance of movement of the triple junction and deformation result in the apparently stationary position of the triple junction.

MINIMUM CURVATURE OF THE PACIFIC PLATE

If the position of the triple junction moved along the Sagami Trough without the deformation of central and southwest Japan, the subductive boundary for the Pacific Plate would have an uncinate process (Fig. 2a). The Pacific Plate in this area is the oldest and thickest of the oceanic plates involved, and it would be a problem for the thick Pacific Plate to subduct along such an irregular boundary with an uncinate process.

The physical properties of a plate should constrain the radius of minimum curvature for the subduction. The plate cannot be bent with a smaller curvature than the minimum radius. The radius can be estimated to be smaller for thin, young oceanic plate than thick, old plate, in the same way that there may be a smaller radius of curvature for a table cloth than for a thick carpet.

If the curvature of the uncinate process is smaller than the radius of curvature, the Pacific Plate should depress the uncinate process or create a space at the boundary. In the case of the triple junction, the Pacific Plate depresses the uncinate process and deforms central and southwest Japan in order to keep the minimum curvature of the thick Pacific Plate subducting along the Izu Trench and the Japan Trench through the triple junction (Fig. 2b).

The subducting boundary of the Pacific Plate has a curvature convex toward the west and the curvature can be traced on a small circle of which the radius is measured to be 396 km. The center of the small circle is located at 34.0°N latitude and 146.3°E longitude. The small circle contacts the Izu Trench at 33.3°N and 142.1°E. The small circle is herein named the "Pacific Small Circle" (Fig. 4).

The westward curvature of the Japan Trench changes to eastward curvature to the north, and the eastward curvature also can be traced on a small circle with the same radius. The center of the small circle is located at 38.6°N and 139.5°E. The small circle contacts the straight part of the Japan Trench at 38.3°N and 144.1°E. The small circle is herein named the "Mogami Small Circle". (Mogami is the name of the area on the Japan Sea side of Honshu where the center of the small circle is located.)

Because the axis from the Izu Trench to the Japan Trench aligns well on the small circles with radii of curvature several times larger than the thickness of the Pacific Plate (Figs. 3 and 4), the mechanism of the deformation of central and southwest Japan can be explained by the deformation of the subductive boundary around the triple junction for retention of the minimum curvature of subduction of the thick Pacific Plate along an irregular boundary (Fig. 4).

BENDING OF THE ZONAL STRUCTURE IN CENTRAL JAPAN

If the margin of the subducted plate were deformed around the Pacific Small Circle to maintain the minimum curvature of the Pacific Plate, the intra-plate horizontal stress field in central and southwest Japan should be directly related to the compressional force.

The crust of central Japan is intruded by island arc magmatism, derived from the subduction of the Pacific Plate. The magmatism heats the crust along the arc and makes it easy to deform.

Central Japan is colliding with the Izu Arc on the Philippine Sea Plate, and the Great Bend of central Japan deviates from a straight line an amount comparable to the amount of motion of the Philippine Sea Plate for the past 7 m.y. (Fig. 1). The northern part of the Izu Arc consists of the colliding Tanzawa and Izu Blocks. The collision of the Tanzawa and Izu Blocks has been thought to be the main process behind formation of the Great Bend (NIITSUMA 1989). However, the apex of the bending structure coincides with the position of the volcanic arc rather than the position of the colliding block of the Izu Arc on the Philippine Sea Plate (Fig. 1). It is much more reasonable that the Great Bend has been formed by collision with the heated weak crust of central Japan and the compressional stress field, induced by the deformation of the plate margin around the Pacific Small Circle (Fig. 4).

EAST-WEST COMPRESSIONAL STRESS IN SOUTHWEST JAPAN

The east-west compressional stress field dominates west of the bending structure in southwest Japan, and large scale coupled active faults are developed in central Japan (Fig. 1).

HUZITA (1980) estimated the E-W trending horizontal compressional stress field to be a result of "effects of the subduction of the Pacific Plate"; however, a mechanical explanation has not yet been

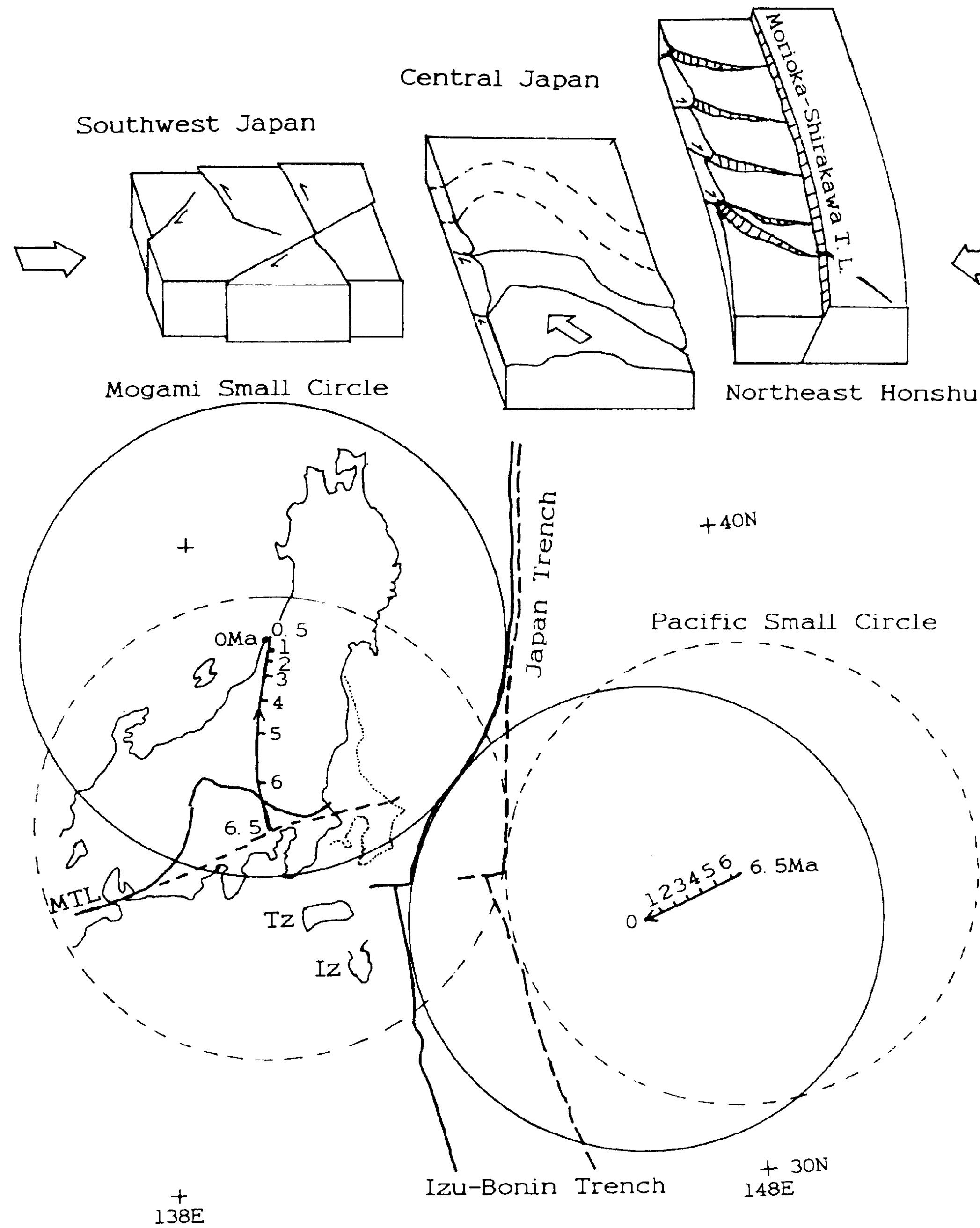


Fig. 4 The Pacific and Mogami Small Circles of present and 6.5 Ma with traces of the center, and tectonic feature of southwest Japan, central Japan and northeast Honshu. Solid line: present plate boundary and MTL (Median Tectonic Line), broken line: plate boundary and MTL at 6.5 Ma, dotted line: position of present coast at 6.5 Ma, Tz and Iz: position of Tanzawa Block and Izu Block at 6.5 Ma.

found. The E-W trend is roughly parallel to the motion of the Pacific Plate (Fig. 1). If the stress field in the subducted plate were controlled by the subducting plate motion, the stress field in central Japan should be affected much more by the northwestward subduction of the Philippine Sea Plate because of the shorter distance. The stress is assumed to be released repeatedly during great earthquakes between the subductive and subducting plates; it is unlikely that the stress would continuously remain uniform along the E-W compressional stress field.

The source of the stress field is reasonably explained by the deformation of the subductive plate margin around the Pacific Small Circle, and the stress is filtered uniformly through the weak heated crust and Great Bend in central Japan (Fig. 4).

TECTONIC EVOLUTION OF NORTHEAST HONSHU

The deformation of the subducted plate margin occurred not only in central and southwest Japan, but also in northeast Honshu. Northeast Honshu has an arc-shape in the southern part (Fig. 1), parallel to the trace of the Japan Trench on the Mogami Small Circle, keeping the minimum curvature of the subducting Pacific Plate. The evolution of the tripl junction requires that the position of the Mogami Small Circle moves northward, and that an arc develops, if the Japan Trench is located on the Eurasian Plate.

The present day plate configuration shows the western slope of the Japan Trench to be located on the North American Plate, which moves westward relative to the Eurasian Plate (Fig. 1). The relative motion of the North American Plate to the Eurasian Plate relates directly to the spreading of the Atlantic Ocean. The motion is comparable to the rate of the retreat of the Izu Trench at the triple junction, which means that the Mogami Small Circle does not move northward, but westward, and the northeast portion of the Honshu Arc is not presently being deformed (Fig. 4).

The boundary of the North American and Eurasian Plates is located in the eastern margin of the Japan Sea (NAKAMURA 1983), but it was located along the Ishikari Lowland of Hokkaido Island, northern extension of the Japan Trench, 0.5 Ma (NIITSUMA & AKIBA 1985). Before 0.5 Ma, the Japan Trench was located on the eastern margin of the Eurasian Plate and the Mogami Small Circle moved northward (Fig. 4). It is suggested that northeast Honshu was deformed from 6.5 Ma to 0.5 Ma. The development of the arc-shape bend induced tectonic movements. KITAMURA (1959, 1963) clarified that northeast Honshu is composed of several blocks bounded with NW-SE and NNW-SSE trending faults and that the blocks were cut by a N-S trending and westward dipping main normal fault, the Morioka-Shirakawa Tectonic Line (Fig. 1). The bend of the main normal fault induced the blocks to imbricate, based on the evolution of sedimentary basins overlying the blocks (Fig. 4). The bend of the N-S main fault corresponds to the northward shift of the Mogami Small Circle.

The Kakkonda Geothermal Area in the central part of northeast Honshu is being explored for the development of geothermal energy, and intensive surveys and drilling have been conducted (Fig. 1). The geothermal area was intruded by granitic intrusives at about 1 Ma (KANISAWA *et al.* 1994). The stress field, examined by the measurements of faults and vein directions, was remarkably changed after the granitic intrusions (KOSHIYA *et al.* 1993). This is consistent with the stop of the development of the arc-shape bend, caused by the shift of the boundary between the Eurasian Plate and North American Plate (Fig. 4).

The tectonic evolution of northeast Honshu has been controlled essentially by the bend of the Morioka-Shirakawa Tectonic Line, and the bend is explained by the deformation of the subducted plate margin around the triple junction.

SUMMARY AND CONCLUSION

The trench-trench-trench type triple junction off the Kanto Plain is a unique point on the present global tectonic framework. The triple junction off the Kanto Plain is related to the motions of the Pacific, Philippine Sea, Eurasian and North American Plates. The subduction of the Philippine Sea Plate has continued for 7 m.y. and the accretion, collision and formation of the forearc basin started along the northern margin of the Philippine Sea Plate.

The topography around the triple junction supports the existence of the hypothesized hole, which has been filled up with the collapsed materials from the plate boundary and turbidites from the Honshu through the Sagami Trough. The axis from the Izu Trench to the Japan Trench aligns well on the Pacific Small Circle and Mogami Small Circle with radii of curvature several times larger than the thickness of the Pacific Plate. The fitting of the trench axis on the small circles can be explained by the deformation of the subductive boundary around the triple junction for retention of the minimum curvature of subduction of the thick Pacific Plate along an irregular boundary with an uncinate process, created by the retreat of the Izu Trench on the Philippine Sea Plate.

The Great Bend of zonal structure in central Japan has been formed by collision with the heated weak crust of central Japan and the compressional stress field, induced by the deformation of the plate margin around the Pacific Small Circle and a balance of movement of the triple junction and deformation result in the apparently stationary position of the triple junction. The source of the east-west compressional stress field in the Southwest Japan is reasonably explained by the deformation of the subductive plate margin around the Pacific Small Circle. The tectonic evolution of northeast Honshu has been controlled essentially by the bend of the Morioka-Shirakawa Tectonic Line, and the bend is explained by the deformation of the subducted plate margin along the Mogami Small Circle.

The most important factors around the triple junction are the retreat of the Izu Trench on the Philippine Sea Plate and the minimum curvature of the Pacific Plate for the subduction along the Japan Trench.

ACKNOWLEDGEMENTS

I thank A. Taira of the University of Tokyo, N. Doi of JMC Geothermal Research & Development and R. Ross of Shizuoka University for useful discussion and reviews.

REFERENCES

FURUMOTO M., KUNITOMO T. & INOUE H. (1989), Depth contour maps of the discontinuity surfaces of the crust in and around the South Fossa Magna. *Modern Geology*, **14**, 35-46.

Geological Survey of Japan (1992), 1:1,000,000 Geological Map of Japan.

HUZITA K. (1980), Role of the Median Tectonic Line in the Quaternary tectonics of the Japanese Islands. *Memoirs of the Geological Society of Japan*, **18**, 129-153.

Hydrographic Department of Japan (1991), 1:2,500,000 Bathymetric Chart "Southern Sea of Nippon".

ISHIBASHI K. & ISHIDA M. (1989), Seismic activity in the South Fossa Magna, central Japan. *Modern Geology*, **14**, 19-33.

ISHIDA M. (1992), Geometry and relative motion of the Philippine Sea Plate and Pacific Plate beneath the Kanto-Tokai District, Japan. *Journal of Geophysical Research*, **97**, 489-513.

KANISAWA S., DOI N., KATO O. & ISHIKAWA K. (1994), Quaternary Kakkonda Granite underlying the Kakkonda Geothermal Field, northeast Japan. *Journal of Japan Association of Mineral, Petrology & Economic Geology*, 89, 390-407.

KITAMURA N. (1959), Tertiary orogenesis in northeast Honshu, Japan. *Contributions from Institute of Geology & Paleontology, Tohoku University*, **49**, 1-98.

KITAMURA N. (1963), Tertiary tectonic movements of the Green Tuff Area. *Fossils*, **5**, 123-137, (in Japanese).

KOSHIYA S., OKAMI K., KIKUCHI Y., HIRAYAMA T., HAYASAKA Y., UZAWA M., HONMA K. & DOI M. (1993), Fracture system developed in the Takinoue Geothermal Area. *Journal of Geothermal Research*, **15**, 109-139.

MCKENZIE D.P. & MORGAN W.J. (1969), Evolution of triple junctions. *Nature*, **224**, 125-133.

NAKAMURA K. (1983), Possible nascent trench along the eastern Japan Sea as the convergent boundary between Eurasian and North American Plates. *Bulletin of Earthquake Research Institution*, **58**, 711-722.

NAUMANN E. (1887), Die Japanische Inselwelt, eine geographisch-geologische Skizze. *Mitth. der kais. koenig. Geogr. Gesells. Wien*, **30**, N.F. 20, 129-138, 201-212.

NIITSUMA N. (in press), Rupture and delamination of island arc crust relating to the arc-arc collision in the South Fossa Magna, central Japan. *Island Arc*.

NIITSUMA N. (1989), Collision tectonics in the South Fossa Magna, central Japan. *Modern Geology*, **14**, 3-18.

NIITSUMA N. & AKIBA F. (1985), Neogene tectonic evolution and plate subduction in the Japanese island arcs. *In*: NASU N., UYEDA S. & KAGAMI H. (eds.) *Formation of active ocean margins*, Terra-publishers, Tokyo, 75-108.

NIITSUMA N. & MATSUDA T. (1985), Collision in the South Fossa Magna Area, central Japan. *Recent Progress in Natural Sciences of Japan*, **10**, 41-50.

Research Group for active faults of Japan (1994), *Active faults in Japan*, University of Tokyo Press, Tokyo, 437p.

SENO T. (1993), A model for the motion of the Philippine Sea Plate consistent with NUVEL-1 and geological data. *Journal of Geophysical Research*, **98**, 17941-17948.

TATSUMI Y. (1989), Migration of fluid phases and genesis of basalt magmas in subduction zones. *Journal of Geophysical Research*, **94**, 4697-4707.