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An introduction to the Cenozoic tectonics of the Japan arc

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RESUMEN

Aún cuando no se conoce con precisión la fecha en que comenzó la apertura del Mar del Japón, ésta probablemente comenzó hace 20 Ma. La deformación del arco japonés entre 18 y 20 Ma hasta hace 15 Ma se llevó a cabo como una respuesta a su cabalgadura sobre la placa Pacífico. La colisión de la placa del Mar de Filipinas contra el SW de Japón (1) detuvo el esparcimiento tanto en el Mar del Japón como en la Cuenca de Shikoku hace 15 Ma, (2) formó una junta triple de trincheras frente a las costas del Japón central y (3) dividió el arco en los arcos del SW y NE de Japón. El arco del SW de Japón ha estado sujeto a deformación compresional desde este evento, mientras que en el arco del NE de Japón se llevó a cabo un cambio de deformación compresional a extensional que comenzó durante el Plioceno.

PALABRAS CLAVE: Tectónica, Cenozoico, arco japonés, riftogénesis, compresión, extensión, geología histórica.

ABSTRACT

Although not well constrained, spreading in the Japan Sea probably began at ~20 Ma; deformation of the Japan arc from 18-20 Ma to 15 Ma was a response to its overriding of the Pacific plate. The collision of the Philippine Sea plate against SW Japan (1) stopped spreading both in the Japan Sea and Shikoku basin at 15 Ma, (2) formed a triple trench junction off Central Japan and (3) divided the arc into the SW and NE Japan arcs. The SW Japan arc has been subjected to compressional deformation since this event, whereas a change from compressional to extensional deformation commenced in the NE Japan arc during the Pliocene.

KEY WORDS: Tectonics, Cenozoic, Japan arc, rifting, compresion, extension, historical geology.

INTRODUCTION

The Japan Sea is about the size of the Basin and Range province and opened in the Miocene. The main island of Japan has a wide land area with a large population—the result is that the Japan arc is the best studied oceanic arc in the world and that a wealth of geological and geophysical data has been accumulated that help us understand island-arc tectonics. The island is divided into the SW and NE Japan arcs by an active fold-and-thrust belt in the Fossa Magna region, central Japan (Figure 1). The collision of the Izu-Bonin arc chopped the proto-Japan arc into two arcs (Hibbard and Karig, 1990). An actively deforming belt extends from the Fossa Magna region through the eastern margin of the Japan Sea where subduction is just beginning (Nakamura, 1983; Seno, 1985).

The Pacific plate was subducting under the Japan arc to form accretionary complexes with Cretaceous-Paleogene magmatism. The accretion process has been going on along the Nankai trough in front of the SW Japan arc (Taira *et al.*, 1989). In contrast, the Japan trench off NE Japan switched to a locus of subduction erosion probably in the Miocene.

PALEOGENE

The basement of the Japan arc is composed of accretionary complexes that have zonal structures along the arc (Isozaki and Maruyama, 1991), parts of which acted as preexistent zones of weakness during later extensional events. Dallmeyer and Takasu (1991) show using ^{40}Ar-^{30}Ar technique that the Sambagawa high-pressure metamorphic belt was uplifted by the Paleocene. The exhumation was the most drastic vertical movement in the Cenozoic Japan arc. Conglomerates derived from the belt are found in the Kuma Group, SW Japan (Nagai, 1972). This group contains large foraminifera, of Eocene age; thus, the Sambagawa belt was exposed before the deposition of the Group. Accordingly, the basement of the Japan arc that was involved later in the rifting of the Japan Sea was probably completed by the Eocene.

NEOGENE AND QUATERNARY

Constraints from marine geology and geophysics

The formation of the Japan Sea was the most drastic horizontal movement in the Cenozoic. The timing of the opening is not well constrained; however rifting most likely started in the Oligocene or earliest Miocene with spreading beginning ~20 Ma. This age is constrained by ^{40}Ar-^{30}Ar dating of the basaltic basement of the basin which was drilled by the ODP leg 127 (Kaneoka *et al.*, 1992).

The Japan Sea has three sub-basins: the Japan, Yamato, and Tsushima (Ulleung) basins which are separated by continental fragments (Figure 1). The Japan Sea is underlain by oceanic crust (Ludwig *et al.*, 1975), though it is controversial whether the crust under the other sub-basins is oceanic. The seafloor of the Yamato and Tsushima basins is shallower than the Japan basin. In addition, the two sub-basins have abnormally thick crust—twice as thick as normal oceanic crust (Hirata *et al.*, 1989).

Magnetic anomalies in the Japan Sea are so chaotic that there is no consensus on their identification (Isezaki and Uyeda, 1973; Isezaki, 1986; Kono, 1986; Tamaki and

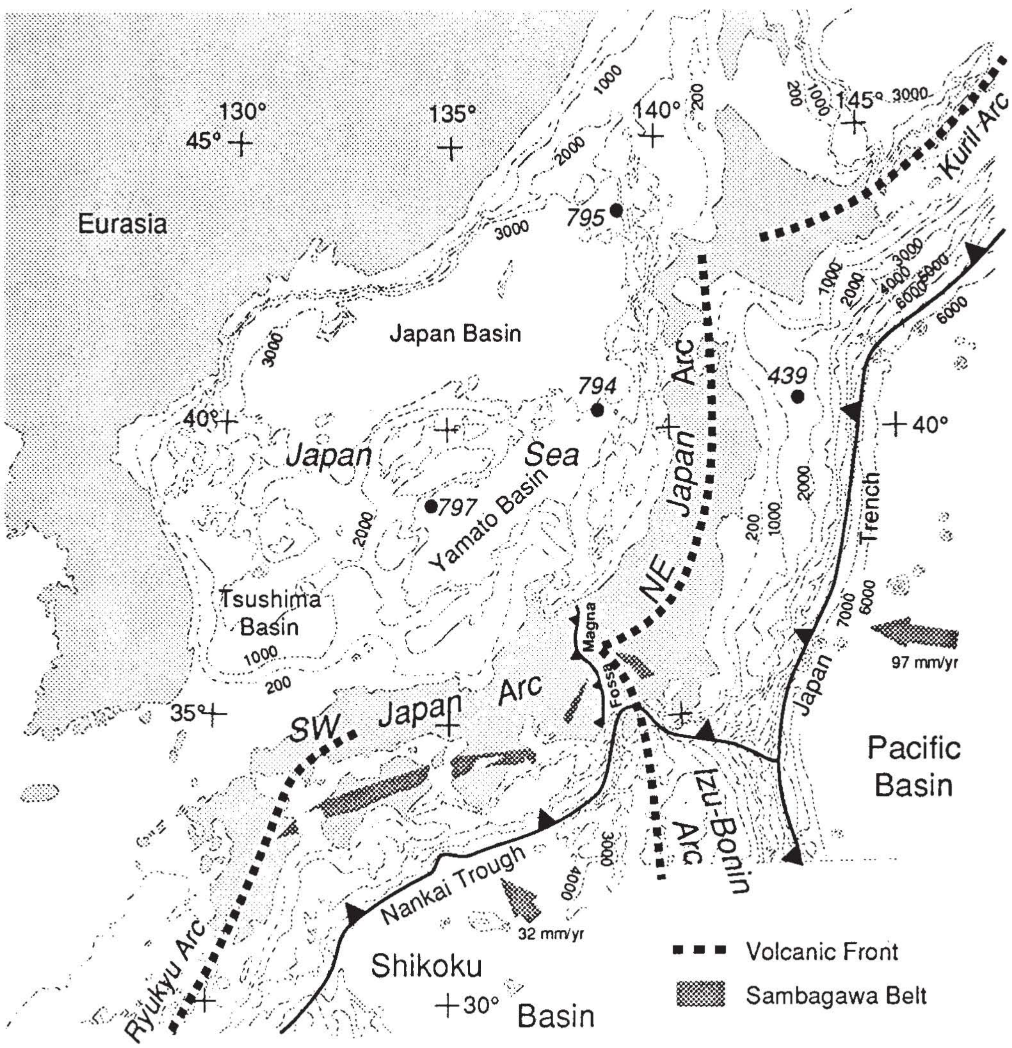

Fig. 1. Tectonic map of Japan.

Kobayashi, 1988; Saema and Isezaki, 1990). These studies assume a constant spreading rate; however, it should be noted that there is no evidence for this assumption, especially for the Japan Sea which may have had a complicated opening history, (e.g. Jolivet *et al.* 1991). Oshida (1993) shows that linear magnetic anomalies are absent from the Yamato and Tsushima basins, suggesting that the basins have thinned continental crust. He also argues on the basis of bathymetry and magnetic anomalies that only a part of the Japan basin is underlain by oceanic crust: the majority being underlain by continental crust.

If this is the case, there is an interesting consequence. Namely, that the basaltic rocks recovered by ODP drilling do not necessarily represent the oceanic basement. This basalt is overlain by early Middle Miocene deep marine sediments, and are found at three sites (794, 795, and 797); the site spacing being ~500 km. Although the drill sites are sparse, basalts comprise the upper part of the acoustic basement that underlies all of the Yamato and Tsushima basins. The magmatism covered a large area within a short period of time around 20 Ma. In other words, a voluminous amount of basalt extruded in the backarc just before, or associated with, the opening of the Japan Sea.

Constraints from onshore geology

Two phases of extensional tectonics are identified in the inner Japan arc: an Eocene-Early Oligocene phase and an Early Miocene phase. However, their relation to the rifting in the Japan Sea is unclear. The earlier phase left a few minor half-grabens in SW Japan (Imaoka *et al.*, 1992; Okamoto, 1965; Ozaki and Matsuura, 1988). None of the half-grabens of this phase are found in the present land area of NE Japan, suggesting that such grabens are buried deep under the continental slope. The second phase of crustal extension began at 18-20 Ma. There are a number of grabens created during this period in NE Japan (Yamaji, 1990) whereas only a small number of grabens are found in SE Japan. This suggests that only a minor amount of lithospheric deformation occurred in SW Japan; consistent with a coherent rotation of the SW Japan as inferred from coherent paleomagnetic deflections in SW Japan. This rotation of SW Japan around 15 Ma is attributed to the opening of the Japan Sea (Otofuji and Matsuda, 1983, 1984). Recent paleomagnetic investigations confirm a rapid rotation of the SW Japan arc (Hayashida *et al.*, 1991; Otofuji *et al.*, 1991).

In contrast, paleomagnetic declinations of pre-Middle-Miocene rocks are not coherent in NE Japan. Although most of them show counterclockwise rotation, the opposite direction is found in places (Otofuji *et al.*, 1985; Momose *et al.*, 1992; Takahashi, 1994). The incoherent declination in tandem with the great number of Early Miocene grabens suggests that the NE Japan arc was broken into blocks which underwent differential rotations in Early Miocene.

The paleomagnetic rotation of SW Japan abruptly stopped at 14-15 Ma (Otofuji *et al.*, 1991). Near-trench magmatism commenced simultaneously along the entire length (~800 km) of the Nankai trough. SW Japan was uplifted from shallow marine to subaerial environment at the same time. These simultaneous events are attributed to the initiation of subduction of the buoyant Philippine Sea plate (Yoshida *et al.*, 1993). Simultaneous with the above events, spreading in the Shikoku basin on the Philippine Sea plate began in the Early Miocene and aborted at 15 Ma (Okino *et al.*, 1993). The collision of the plate with the SW Japan arc may have blocked spreading both in the Japan Sea and in the Shikoku basin. In contrast, the NE Japan volcanic arc remained deeply submerged through the Middle Miocene.

The SW Japan arc was subject to compressional deformation soon after the termination of backarc opening, as is evidenced by the syndepositional folding of Middle to Late Miocene sediments off the San'in district, southern Tsushima basin (Tanaka and Ogusa, 1981). The folded layers are truncated by a Pliocene sequence forming an angular unconformity; yet transpressional deformation was also going on.

The NE Japan extensional deformation terminated at ~16 Ma (Yamaji, 1994). The volcanic arc submerged to middle or lower bathyal depths (500-2500 m) by 15 Ma (Yamaji and Sato, 1989; Hasegawa *et al.*, 1989; Yamaji 1990), whereas the present Pacific coast remained near sea-level. The submerged volcanic arc rose above sea level in the Late Miocene forming a chain of cauldrons (Sato and Amano, 1992). Compressional tectonics commenced in the Pliocene and is still going on (Sato and Amano, 1992).

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