Why are there no back-arc basins around the eastern Pacific margin?

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ABSTRACT

There are many back-arc basins (system of island arc and back-arc seas) on the western margin of the Pacific Ocean, but we do not find any back-arc basins on the eastern of the Pacific margin even though volcanism related to subducting slabs has been operating on both sides of the Pacific. It seems that subduction of oceanic plates contributes to volcanism not only through the supply of slab-derived fluids necessary for upwelling of magma diapirs, but also by inducing convention in the mantle wedge so as to maintain the hot mantle layer within the wedge. Dehydration from the hydrous layer of old descending slabs at depths of 100 to 300 km is important for the genesis of volcanic chains and back-arc spreading. In contrast, dehydration from the hydrous layer of young descending slabs acts quite differently on the origin of volcanism. These differences are shown by the examination of high pressure and high temperature phase changes in MORB (mid-oceanic ridge basalt) + H_2O reactions.

Keywords: back-arc basins, Pacific Ocean, subduction.

RESUMEN

Existen muchas cuencas tras-arco (sistema de arco insular y mares tras-arco) en el margen occidental del Océano Pacífico, pero no se encuentra ninguna cuenca tras-arco en la parte oriental del margen pacífico, aún cuando el volcanismo relacionado a placas que subducen ha estado operando en ambos lados del Pacífico. Aparentemente la subducción de placas oceánicas contribuye al volcanismo no sólo con el suministro de los fluidos derivados de la placa necesarios para el ascenso de diapiros de magma, sino también por la inducción de movimientos convectivos en la cuña del manto que mantienen la capa de manto caliente en la cuña. Durante la subducción, la deshidratación de la capa hidratada de placas antiguas a profundidades de 100 a 300 km es importante en la génesis de cadenas volcánicas y de la expansión tras-arco. En contraste, la deshidratación de la capa hidratada en placas jóvenes durante la subducción actúa de manera muy diferente en el origen del volcanismo. Esas diferencias se muestran al examinar los cambios de fase a alta temperatura y presión en reacciones de MORB (Basaltos de dorsal oceánica) + H_2O.

Palabras clave: cuencas tras-arco, Océano Pacífico, subducción.

INTRODUCTION

The Indonesian and Japanese arc volcanism has been discussed in *e.g.* Nishimura and Suparka (1988) and Nishimura (1998, 2000) from the geological and geophysical perspectives. Drawing on plate tectonic studies of the Indonesian and Japanese arcs, geophysical, geochemical and geological data have been synthesized to constrain models of plate tectonic evolution.

Volcanic belts on the western side of the Pacific Ocean consist of three series, namely, the tholeiite, high-alkali tholeiite and alkali-basalt series (Nishimura, 1998, 2000); but the eastern side of the Pacific contains one or two series (Tatsumi, 1995; Tatsumi and Eggins, 1995). Okamoto *et al.* (1997) discussed the differences in dehydration processes of subducting slabs with different ages.

There are also discussions on the ages of oceanic plates (*e.g*., Pitman *et al*., 1974). These studies show that old and young slabs exist on the western and eastern margins of the Pacific, respectively.

This paper demonstrates the relation between subduction-related volcanism and the age of the subducting slab, and their tectonic implications for the presence or lack of back-arc basins on the Pacific margin.

AGES OF PACIFIC OCEAN PLATE

A map of ages of Pacific Ocean plate and marginal basins are shown in Figure 1. According to this map, the ages of subducting slabs around the western Pacific margin are older than those around the eastern Pacific margin.

MAGMATISM IN THE MANTLE WEDGE

Tatsumi (1989) discussed the magmatic processes in the mantle wedge in subduction zones. Amphibole and chlorite are dehydrated at depths of ~100 km in the dragged hydrated peridotite just beneath the volcanic front. The dehydration occurs for phlogopite at depths of 150 km, and for lawsonite-eclogite at depths of 250-300 km (Figure 2). Through these processes, subduction components held in these hydrate materials are released with H_2O, although part of them may be transported to deeper levels.

Since 1980, various hydrous metamorphic rocks has been examined around the world. On the basis of these results, Okamoto *et al.*(1997) discussed the relations between age (young and old) of subducted slabs and releases of H_2O at various pressure-temperature conditions (Figure 3).

The H_2O released from the slab migrated upward, *i.e.* toward the lower pressure (shallower) zones of upper mantle. At a certain depth, the front of H_2O or the front of decomposition of amphibole and chlorite cuts the geotherm of 1,000ºC, that is the solidus temperature of peridotite under H_2O-saturated conditions independent of pressure, hence the partial melting of hydrous

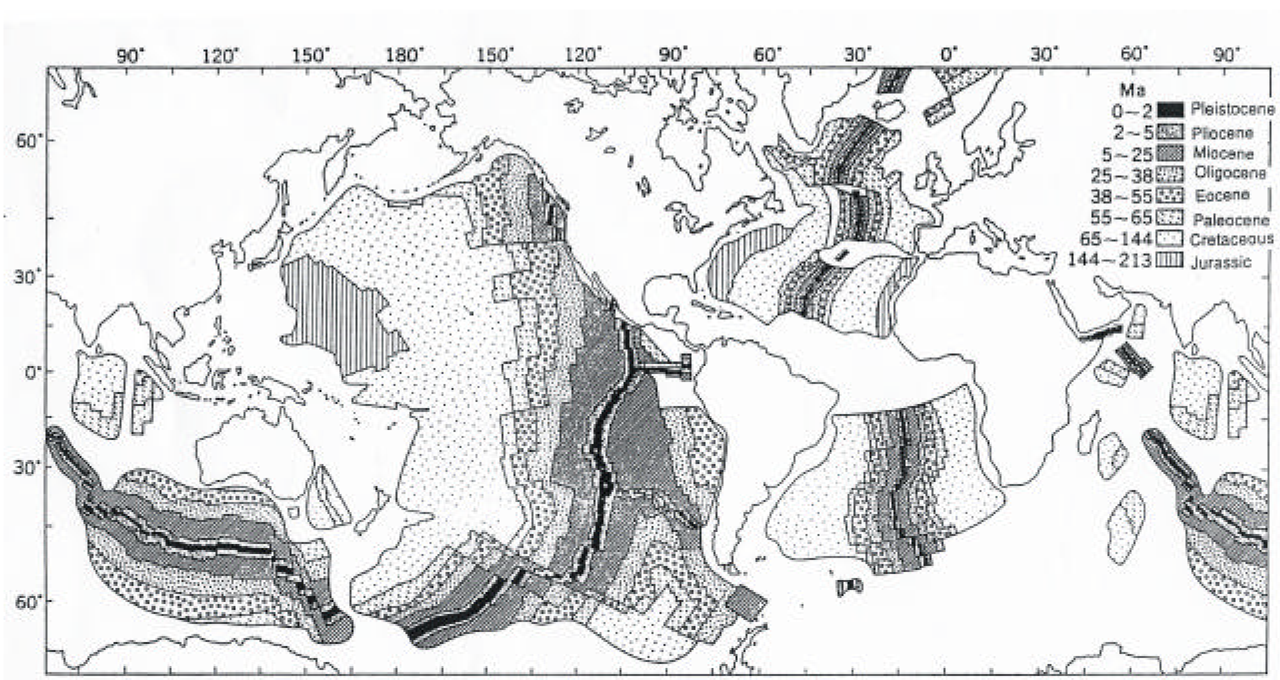

Figure 1. Isochron and age map of ocean basins and marginal basins (modified from Pitman *et al*., 1974, and Tamaki and Honza, 1991).

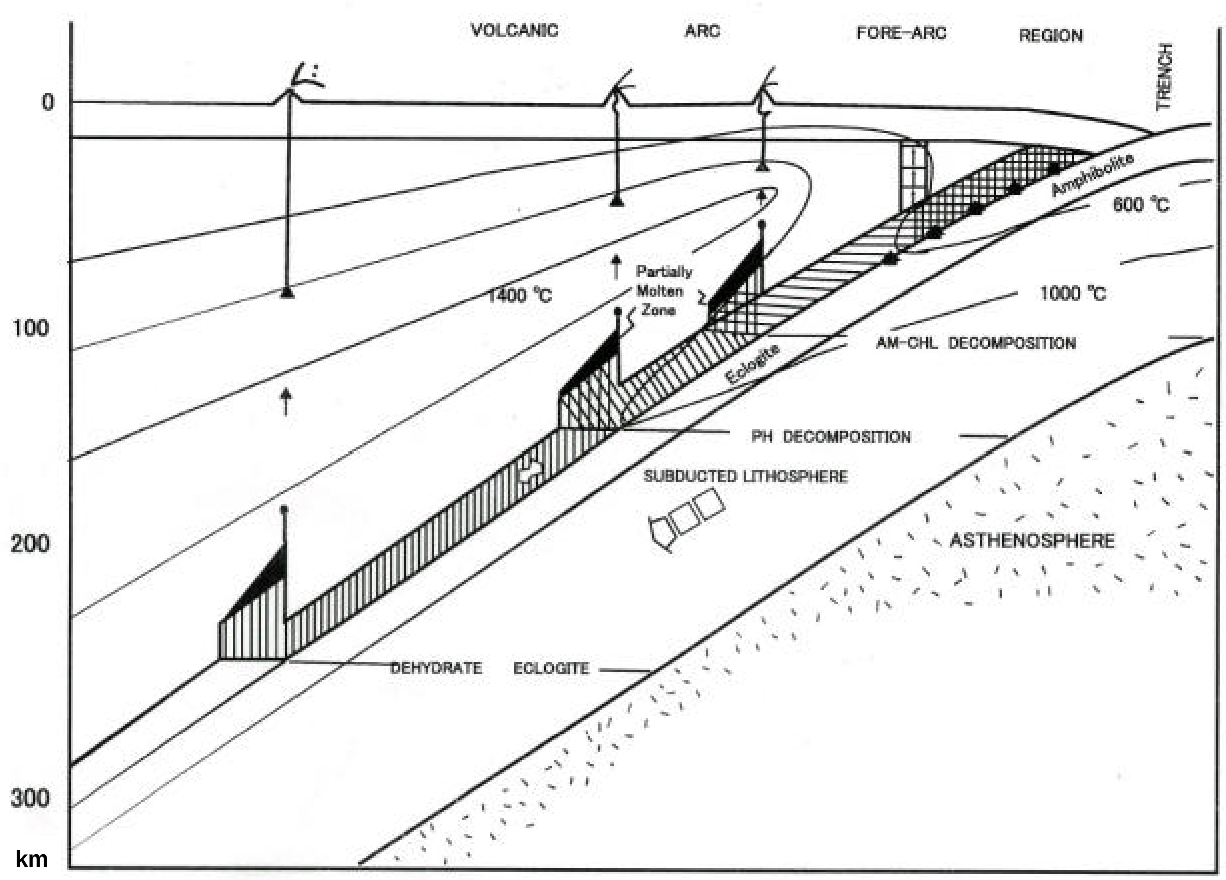

Figure 2. A plausible model for the migration of H_2O and the generation of basalt magmas in subduction zones. The hydrated slab are formed by addition of slab-derived H_2O (solid arrows) beneath the fore-arc region and should be dragged downward on the slab by the subduction of the oceanic plate. Amphibole (AM) and chlorite (CHL) in the dragged hydrated peritotite layer decompose to release H_2O at around 100 km just beneath a volcanic front, phlogopite (PH) decompose at around 150 km depth, and lawsonite-eclogite decomposes at around 250-300 km depth beneath the back-arc side of a volcanic arc. When the hydrated peridotite reaches the region with the solidus temperature of hydrous peridotite, partial melting takes place to produce initial magmas. Successive addition of H_2O to the region expands the partially molten zone upwards, and the degree of partial melting in this zone increases upwards. From the top of the partially molten zone a mantle diapir starts rising. The mantle diapirs must go through the region with temperatures higher than 1,400ºC and stop rising to release primary magmas. The depth of magma segregation from a mantle diapir is deeper in the back-arc side. It should be pointed out that the solidus temperature of hydrous peridotite cannot be attained in normal subduction zones. It follows that no magma can be produced by partial melting of the hydrous column beneath the fore-arc region (modified from Tatsumi, 1989).

peridotite takes place.

Since the partial melt is saturated with H_2O, the H_2O which is successively supplied by the dragged hydrated peridotite, migrates upward in the partial melt as hot vapor phase to hotter regions. Though these processes, a partially molten region expands toward shallower levels, indicating the formation of a partially molten column. The degree of partial melting in the column increases in the upper part, because the column grows towards shallower and hotter regions.

Sakuyama (1983) and Tatsumi *et al.* (1983) proposed that subduction zone magmas may be transported upward by mantle diapirs for the following reasons: 1) there is a limited life span for each volcano due to cooling of a mantle diapir by heat loss toward the surrounding cooler mantle; 2) temperatures of about 1,300ºC beneath the crust-mantle boundary are required for the generation of primary magmas along a volcanic front. If temperature is distributed as a stationary geotherm at such shallow level, the region must melt at more than 20%; however, there is no geophysical evidences for such a large scale of melting. The mantle diapir must go through up in the high temperature region (over 1,400ºC) and stops rising to release a primary magma at about 1.1 GPa beneath a volcanic front (Tatsumi *et al.*, 1983).

Beneath the back-arc regions, H_2O is supplied by the decompositions of phlogopite and lawsonite-eclogite in the dragged hydrated peridotite at the base of mantle wedge (Figure 2). Processes forming partially molten columns and mantle diapirs are the same as those beneath a volcanic front. On the other hand, mantle

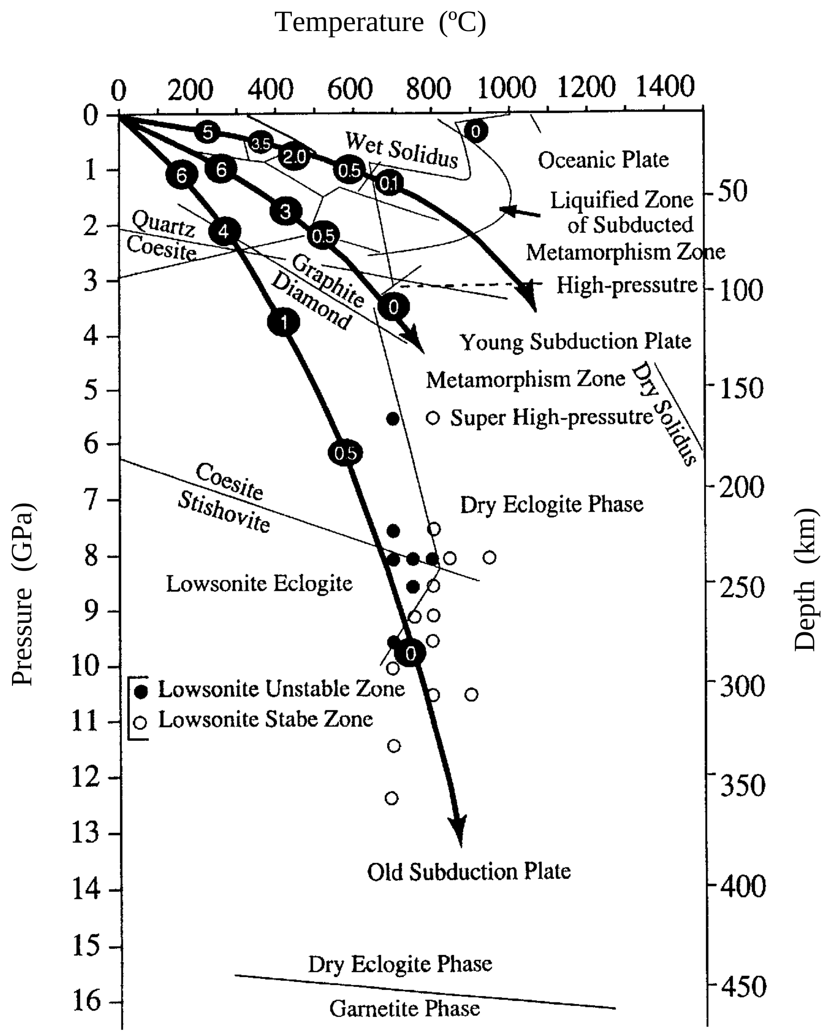

Figure 3. Mid-oceanic ridge baslt (MORB) - H_2O phase diagram (modified from Okamoto *et al.*, 1997). Numbers in circles show the weight percent of H_2O in the subducted slab. The downward dragged hydrous slabs can release H_2O into the mantle, but young subducted slabs could not release H_2O into the mantle, as they melt itself at shallow depth.

diapirs in the back-arc region separate primary magmas at deeper levels (Figure 2), as has been indicated by Okamoto *et al.* (1997) based on melting phase relations at high pressures for primary basalt magmas.

The hydrated peridotite layer can supply H_2O to the overlying mantle wedge at Northeast Honshu, Japan arc. In this case, three volcanic series are observed. Okamoto *et al.* (1997) shows the difference in the dehydration processes of young dragged hydrated peridotite at the base of mantle wedges. In this case, the various volcanic series could not be observed.

The end of dragged old hydrated slabs at the subduction zone undergoes drastic dehydration when it reaches at the depth the volcanic front. This process probably triggers events of back-arc spreading as illustrated by the Japan Sea.

CONCLUSIONS

Subduction of oceanic plates gives rise to the island arcs. However, the nature and behavior of continental margin volcanism is controlled not only by the supply of slab-derived fluids to the upwelling diapirs, but also by inducing convection in the mantle wedge so as to maintain the hot mantle layer within the wedge. When the end of an old hydrated slab reaches beneath the volcanic front, H_20 is supplied to the mantle wedge by decomposition of hydrated minerals, which triggers the formation of back-arc spreading and basins. This process is true for the western margin of the Pacific. In contrast, the eastern margin of Pacific is affected by young subducting slabs, which could not cause back-arc spreading.

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