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Serpentinite Seamounts and Hydrated Mantle Wedge in the Izu-Bonin and Mariana Forearc Regions

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Abstract

Recent studies of forearcs in the circum-Pacific regions have revealed that the widespread serpentinization of mantle wedge peridotite occurs along the subducting slab at depths of 15-30 km due to water supplied from the slab. A huge zone of diapiric serpentinite seamounts along the trench axis in the Izu-Bonin and Mariana forearcs suggests that voluminous and gravitationally unstable low-density serpentinites generated just above the subducting slab have risen to the seafloor to form the seamounts. During ODP Leg 125, metamorphic rock clasts recovered from Holes 778A and 779B at Conical seamount, one of the serpentinite seamounts, have provided essential information on the interaction between forearc material and water. A geochemical study of the 778 A metabasalts indicates that the rocks have a chemical affinity with mid-ocean ridge basalts, some of which have zigzag REE patterns due to intense interaction with seawater. There are two possible origins that are worth considering. One is the trapped oceanic crust in the area between the trench and the volcanic front when subduction of the Pacific plate started, and the other is the accreted oceanic crust supplied directly from descending oceanic slab during subduction. The Hole 778A metabasalts commonly contain quartz veins, which have been produced prior to or during blueschist facies metamorphism, because high-pressure minerals, lawsonite, pumpellyite, and aragonite, were often crystallized in the vein. When the trapped or accreted oceanic crust had been squeezed deep down by the subducting slab, it encountered the pelagic sediments on top of the subducting slab. The SiO_2-rich fluids having permeated the Hole 778A rocks were probably derived from these pelagic sediments. A phengite-rich clast, the only clast recovered from Hole 779B, is ultrabasic in composition, but is rich with incompatible elements, such as Zr, Ti and Th, and is relatively poor in compatible elements, such as Cr , Ni, and Co. Rocks with similar geochemical characteristics are found in the metasomatic reaction zone developed at the boundary between serpentinite and pelitic schist in the high-pressure Sanbagawa metamorphic belt, Japan. The clast may have been formed at the boundary between mantle wedge peridotite and subducting slab, where the hydrothermal metasomatic reactions have pervasively occurred between mantle wedge and pelagic sediments.

Keywords: serpentinite, blueschist, Mariana, forearc, subduction zone

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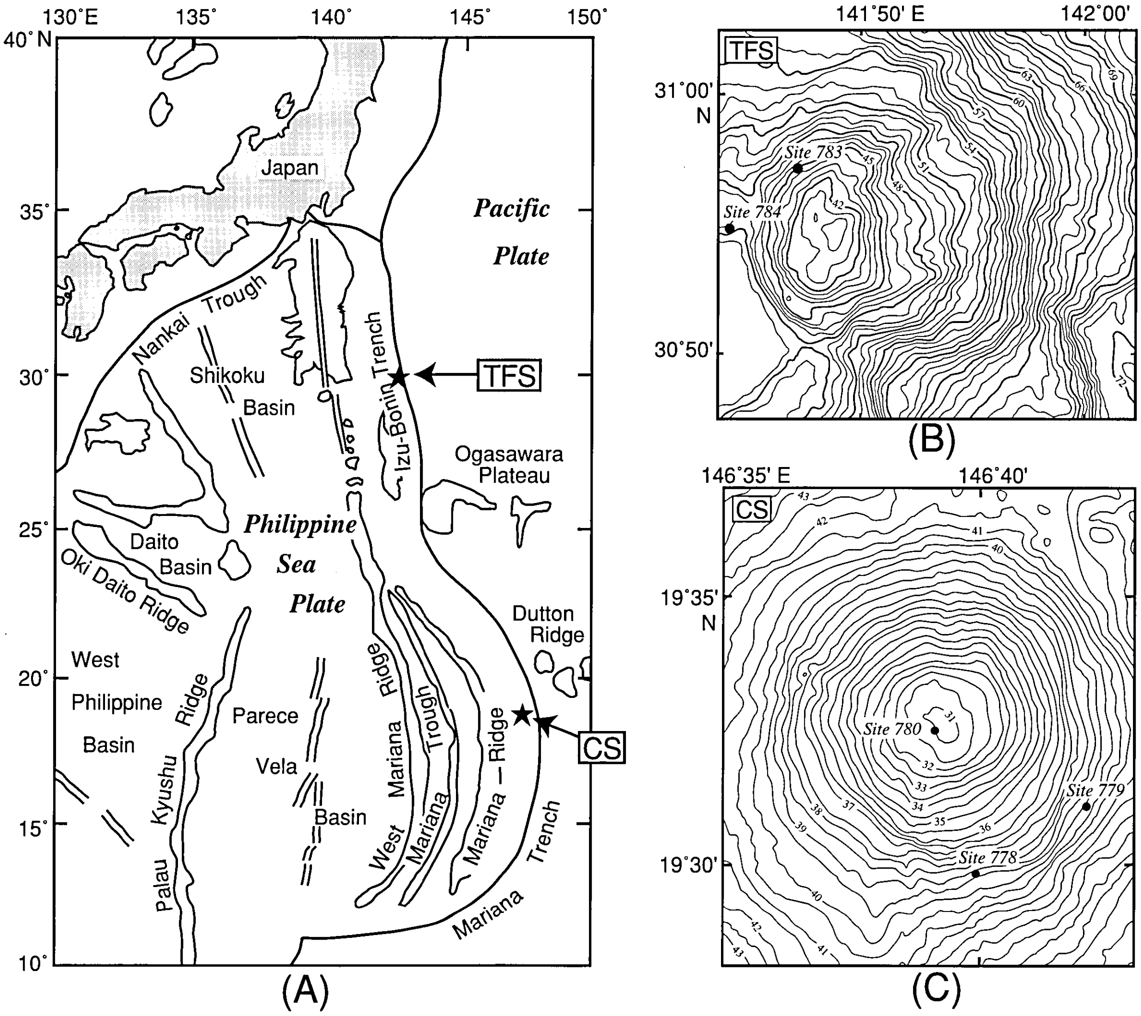

Fig. 1. (A) Regional map of the western Pacific Ocean. TFS: Torishima forearc seamount, CS: Conical seamount. (B) Bathymetric contour map of the Torishima forearc seamount, showing the positions of drilling sites 783 and 784. Contour interval=75 m. (C) Bathymetric contour map of the Conical seamount, showing the positions of drilling sites 778, 779, and 780 (from Fryer *et al.*, 1990). Contour interval=100 m.

1. Introduction

Dredging and drilling in the circum-Pacific regions have revealed that serpentinized peridotites are often exposed in the non-accretionary convergent plate margins (e.g. Fisher and Engel, 1969; Hawkins *et al.*, 1972; Bloomer and Fisher, 1987; Ogawa *et al.*, 1985a and 1985b; Honza and Kagami, 1977; IGCP Working Group, 1977; Fryer *et al.*, 1985; Ishii, 1985; Fryer, 1996, Fryer and Fryer, 1987; Fujioka *et al.*, 1995). In the Izu-Bonin (=Ogasawara) and Mariana forearcs, enormous amounts of serpentinized peridotite have intruded from the mantle wedge to the seafloor to form an array of seamounts (Fryer *et al.*, 1985). Fryer *et al.* (1990) described the fluids seeping from the chimneys at the summit of Conical seamount, one of the forearc seamounts, and indicated that the fluids were derived from the dehydration processes of descending oceanic slab. During Ocean Drilling Program (ODP) Leg 125, small clasts of high-pressure/low-temperature blueschist facies metabasalts were recovered from Conical seamount. This suggests blueschist facies metamorphism beneath the forearc (Maekawa *et al.*, 1992 and 1993). Recent discoveries of blueschist-facies rocks and sediments including fragments of blueschist-facies minerals from other forearc seamounts suggest that the blueschist-facies rocks are rather common in the Izu - Bonin and Mariana forearc seamounts (Maekawa, 1995; Fryer *et al.*, 1999). Understanding the behavior of slab-derived fluids in the processes of mantle wedge serpentinization and metamorphism is important, because the fluids should be one of the main controlling factors of subduction dynamics, which could govern the modes of material transport and earthquakes in the subduction zone. In this paper, we examine the modes of occurrence of forearc seamounts and petrological characteristics of serpentinized peridotites and associated rocks constituting the seamounts, and discuss the role of water squeezed from the subducting slab in the formation of serpentinite seamounts.

2. Topography and general features of the forearc seamounts

In the Izu-Bonin and Mariana forearc regions, a chain of seamounts occurs 50 to 120 km east of the trench axis (Fryer *et al.*, 1985). It extends north to south for more than 2,500 km along the trench axis. The seamounts are commonly dome-like in shape, and are up to 30 km in diameter with up to 2 km of relief. They are composed mainly of serpentinized peridotite. Two seamounts were drilled during ODP Leg 125. One is Conical seamount, which is about 80 km west of the trench axis in the Mariana forearc, and the other is Torishima forearc seamount, which is 40 km west of the Izu-Bonin trench (Fig. 1A). These two seamounts are in marked contrast with each other in topography, geochemistry of interstitial fluids, and formation age. The features of these two seamounts are summarized as typical examples of forearc seamounts as follows.

Conical seamount with a smooth-sided dome-like shape is one of the youngest forearc seamounts in the Mariana forearc, and covers an area of approximately 700 km^2(Fig. 1C). Sidescan sonar images show long sinuous flow features on its flanks (Fryer *et al.*, 1995). Alvin submersible dives on the flank of Conical seamount revealed that serpentinite blocks of varying sizes are scattered in serpentinite mud on the surface of the seamount. The core samples of serpentinites from ODP Leg 125 are highly sheared, and show block-in-matrix fabrics, which are typical in on-land serpentinite melanges (Fig. 2). Carbonate and silicate chimneys up to 1.5 m high are formed on the southwest side of the summit (Fryer *et al.*, 1990). The fluids actively seeping from the chimneys and pore fluids from the summit drill samples are characterized by high pH and less concentrations chloride and bromide than one-half of seawater, and contain methane, ethane, propane, acetate, and organic acids (Haggerty and Fisher, 1992; Mottl, 1992). They probably have the highest pH value ever measured in deep-sea sediments, up to 12.6, and have lower chlorinity than at any other site drilled in a subduction zone, up to 57% lower than that in seawater (Mottl, 1992). The presence of aromatic compounds in the chimneys and of ethane and propane along with methane in the pore waters indicates a thermogenic origin for the organic compounds. The presence of acetate ion limits the temperature range in the source region of the organic materials to less than 150℃. Taking the tectonic environment of the Mariana subduction system into account, the most likely source of sediments is the top of the subducting slab about 30 km below Conical seamount (Mottl, 1992). The Mariana forearc was intensively destroyed by many faults caused by tensional stress and has a characteristic topography of predominant graven and horst structures (Fryer *et al.*, 1985 and 1999). Fryer *et al.* (1995) demonstrated that the serpentinites generated just above the subducting slab have uplifted along the faults to form a huge chain of seamounts on the ocean floor. However, there is still no explanation why the serpentinite dykes have not developed along the faults in the forearc area. Sediments recovered during drilling at the flanks of the seamount contain Pleistocene nannofossils (< 1.6 Ma) (Ciampo, 1992), suggesting the recent uplift of serpentinite materials to the seafloor. As demonstrated before, the fluids that converted peridotite to serpentinite are still actively upwelling from the chimneys at its summit. According to Fryer *et al.* (1996), Newsom (1992) carried out gravity study and reported unusually low densities of 2.0 to 2.2 g/cm^3 for Conical seamount. This is consistent with the idea that solid serpentinite fragments are supported by a water-saturated low-density matrix. The seamount shows no coherent internal reflectors on seismic profiles (Fryer *et al.*, 1990). Drilling records from Conical seamount during ODP Leg 125 indicate that drilling rate and degree of serpentinization of peridotites decrease gradually with the drilling depth; that is, higher density and larger blocks tend to accumulate at the lower portion (Fig. 3).

Torishima forearc seamount is located on a lower forearc terrace of the Izu-Bonin inner trench slope. The seamount is slightly asymmetrical and shows a distorted shape (Fig. 1B). The western flank of the seamount is relatively smooth, but the eastern flank is cut by several ridges and valleys oriented northeast-southwest (Fryer *et al.*, 1995). Seismic reflection profiles across the seamounts reveal an acoustically chaotic basement with thin or no sediment cover, and show no coherent internal faulting (Horine *et al.*, 1990; Kamiura *et al.*, 2000). Abundant serpentinized harzburgite and subordinate amounts of metamorphosed gabbro, dolerite, basalt, and their sedimentary derivatives were recovered by dredges (Ishii *et al.*, 1989). Sediments obtained at the flanks of the seamount (Hole 784A) during ODP Leg 125 contain middle Miocene to upper Miocene diatoms (Xu and Wise, 1992; Stabell, 1992) and middle Miocene to early Pleistocene radiolarians (Wang and Yang, 1992). This suggests that the age of formation of Torishima forearc seamount is much older than that of Conical seamount. The pore fluids from the Torishima forearc seamount contrast greatly with those recovered from the summit of Conical seamount. Mottl (1992) reported that the pore fluids sampled by drilling at the flank of Torishima forearc seamount have pH up to 10, very low Si, Mn, and methane, and no ethane or propane. Relative to seawater, they have low alkalinity, sulfate, Mg, K, and B; slightly lower Li and Rb; unchanged Cl, Br, Na, and Na/Cl; and high Ca, Sr, Ba, and ^{34}S. Unlike the fluids from Conical seamount, the fluids from Torishima forearc seamount were produced by the reaction of seawater with harzburgite at low temperatures.

Fig. 2. A core sample recovered from ODP Leg 125 Hole 778A. Serpentinite fragments (black parts) are scattered in the highly sheared and crushed serpentinite matrix.

3. Constituents of the forearc seamounts

According to dredging, drilling, and submersible observations, the forearc seamounts are composed mainly of serpentinized peridotites and contain metamorphic rocks mainly of basaltic compositions. Followings are descriptions of the various rocks obtained from the forearc seamounts.

[Ultramafic rocks]

Ultramafic rocks obtained from Conical and Torishima forearc seamounts are mainly harzburgite with subordinate dunite, which are more depleted than the abyssal peridotites from the mid-oceanic ridge (Ishii *et al.*, 1992 and 2000). They were often highly tectonized. Common occurrence of kink bands in olivine and pyroxene crystals provides evidence of penetrative deformation. All of them are serpentinized to some degree. Serpentine minerals are antigorite, chrysotile, and lizardite (Saboda *et al.*, 1992). In addition to these minerals, serpentinized peridotites often contain brucite, and rarely contain

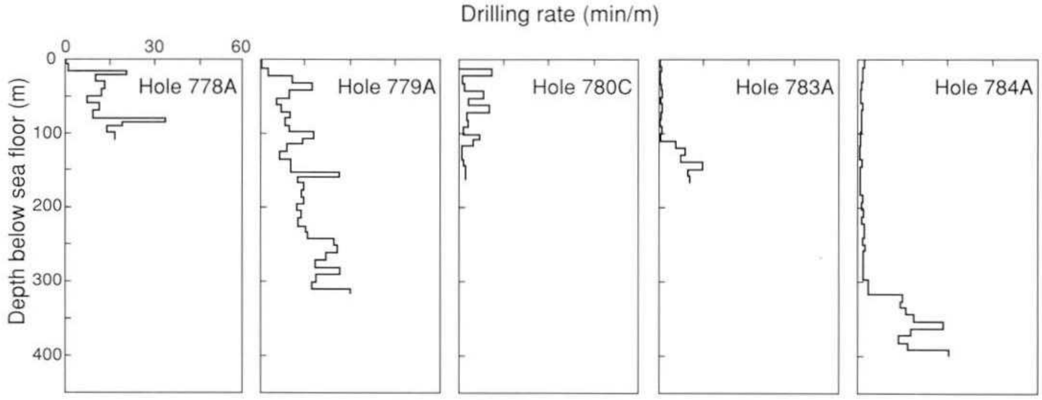

Fig. 3. Relations between drilling rate and depth at the drilling holes of Conical seamount (Holes 778A, 779A, and 780C) and Torishima forearc seamount (Holes 783A and 784A) (Ban, 1991). Vitric and/or plagioclase-rich silt to claystone about 100 m thick covers Site 783A and 300 m thick covers Site 784A.

small amounts of acicular diopside and tremolite. Antigorite is commonly associated with brucite. Two types of serpentine mineral assemblage are recognized in serpentinized peridotites: one is antigorite bearing and the other is antigorite free. In rocks with the former association, chrysotile and lizardite also occur in vein or matrix as later-stage secondary serpentine minerals. Antigorite is stable at higher temperatures than chrysotile (Ishii and Saito, 1973; Evans *et al.*, 1976), and lizardite is considered to have the same P-T stability field as chrysotile (Peacock, 1987). Stable association of antigorite and brucite gave a stability range of 300℃-450℃ (Evans *et al.*, 1976). Further rigorous study of the mineral parageneses of serpentinized peridotites is necessary to obtain reliable P-T conditions of serpentinization and understand the multi-stage history of serpentinization.

[Metabasalts]

Metamorphic rock clasts recovered from Conical seamount during ODP Leg 125 are quite important in consideration of their metamorphic protoliths and to elucidate how they had been incorporated into serpentinites. Approximately 60 metabasalts have been recovered from Hole 778A, approximately 50 from Hole 779A. Most of these rocks occur as pebble-size clasts of a subrounded shape in a serpentinite matrix, but Hole 779A contains a continuous section of metabasalt more than 3 m length. All clasts from Hole 779 A are composed of metamorphic minerals of a low-pressure type (Maekawa *et al.*, 1992). Typical high-pressure minerals, such as lawsonite, sodic pyroxene, and aragonite, were commonly found in metabasalts from Hole 778A (Maekawa *et al.*, 1992) (Fig. 4A). The diagnostic mineral assemblage of the Hole 778A metabasalts is lawsonite + pumpellyite + hematite. Analyses using Schreinemakers' method suggest that the stability field of this assemblage is situated in the lower pressure and lower temperature field of the blueschist-facies conditions; these rocks have been formed under the incipient blueschist-facies conditions (Maekawa *et al.*, 1995). The approximate metamorphic conditions are estimated at about 150 - 250℃ and 5 - 6 kb. Protoliths, identified from their primary textures and mineralogy, are predominantly aphyric to fine-grained basalts and their clastic equivalents. Geochemical studies indicate the metabasalts include rocks having a chemical affinity with mid-ocean ridge basalts (Johnson, 1992; Yamamoto *et al.*, 1995). Yamamoto *et al.* (1995) found that some metabasalts have zigzag REE patterns, reflecting the lanthanide tetrad effect, suggesting intense interaction with seawater.

[Phengite-rich clast]

One metamorphic clast containing abundant phengite was retrieved from Hole 779B (125-799B-01 R-06, 19-22). This clast is composed mainly of phengite, chlorite, and chrysotile, with subordinate amounts of amphibole, pumpellyite, sodic pyroxene, epidote, titanite, rutile, apatite, and zircon (Fig. 4B). K-Ar ages for phengite are about 48 Ma (Maekawa *et al.*, in prep.). Amphiboles are of pargasite to magnesiohastingsite of Leake (1997). Sodic pyroxenes have 19-20 mole percent of jadeite components and are plotted on the aegirine field.

Similar mineral assemblages are observed in the metasomatic reaction zone between serpentinite and pelitic schists in the Sanbagawa high-pressure metamorphic terrane, Japan. The reaction zone in the Sanbagawa terrane is commonly divided into three zones: chlorite zone, tremolite zone, and talc zone, in the order from pelitic schist side toward serpentinite. Our study on the metasomatic reaction zone indicates that pelitic schists and chlorite zone rocks contain significant amounts of incompatible elements, Zr, Ti, and Th, and are relatively poor in compatible elements, Cr, Co, and Ni. On the other hand, serpentinites, talc zone rocks, and tremolite zone rocks are rich in Cr, Co, and Ni, and are highly depleted in Zr, and Th. Fig. 5 shows an example of the relations of these elements in pelitic schists, serpentinites, and metasomatic reaction zone rocks. Fig. 5 suggests that elements such as Cr and Zr seems to be less mobile even when subjected to metasomatic processes. The original boundary between pelites and serpnetinite probably corresponds to the boundary between chlorite zone and tremolite zone. The chlorite zone rocks have similar mineral assemblages to the Hole 779B clast and consist of chlorite, phengite, tremolite and minor titanite, zircon, apatite, and aranite.

Estimating the protolith of the Hole 779B clast is difficult because of chemical migration during the metasomatic reactions. However, the results of studies of the 779B clast mineralogy and the metasomatic reaction zone mentioned above suggest that the Hole

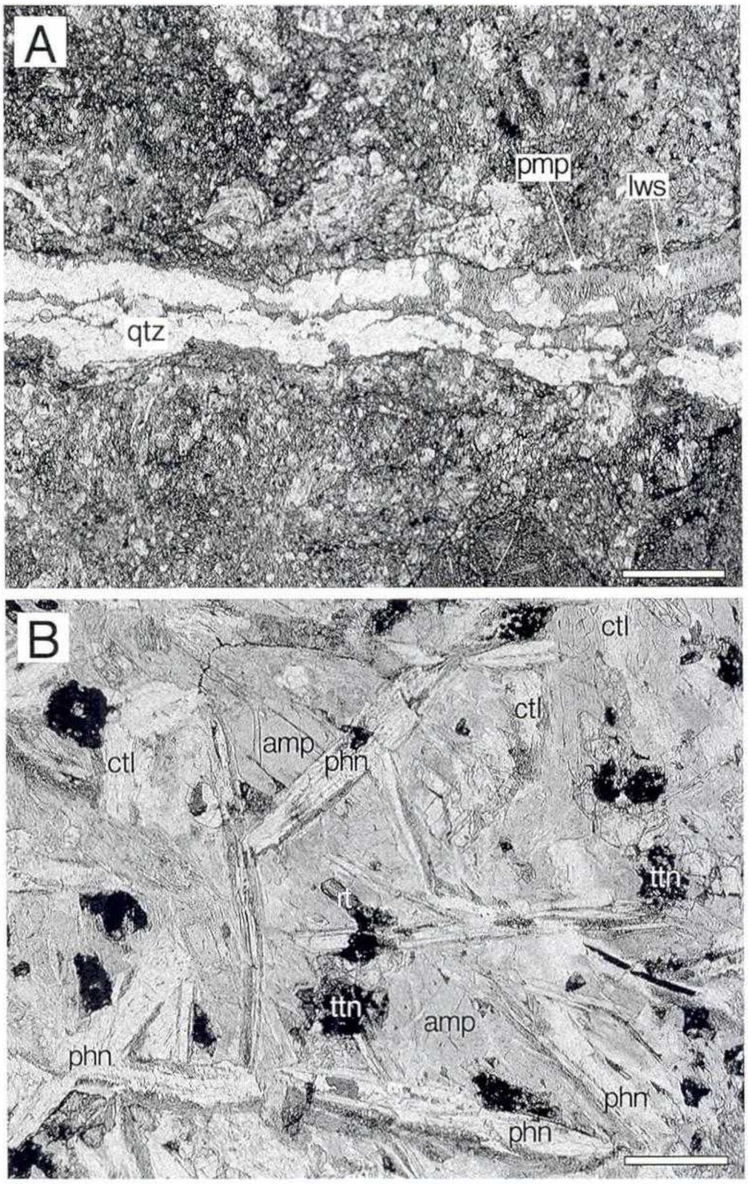

Fig. 4. Photomicrographs of the metamorphic rocks from Conical seamount under optical microscope. (A) Metabasalt (778A6R-1, 10-13). Quartz veins are common in this rock. Pumpellyite, lawsonite, and metamorphic aragonite are often found in quartz veins. qtz: quartz, pmp: pumpellyite, lws: lawsonite. Scale bar is 0.5 mm. (B) Phenite-rich clast (779B1R6, 19-22). phn: phengite, amp : amphibole, ctl: chrysotile, ttn: titanite, rt: rutile. Scale bar is 0.2 mm.

779B clast has at least crust materials, probably pelagic sediments, and formed during metasomatic processes with serpentinites under high-pressure conditions. The presence of abundant phengite and minor zircon in the clast is characteristic of metapelites. The clast totally lacks minerals that contain compatible elements, Ni, Co, and Cr. This may again suggest a pelite origin for the clast. The clast does not contain quartz, which is one of the common constituents of pelitic rocks. The SiO_2 component is considered to have been dissolved during metasomatism, because of the high solubility of SiO_2.

4. Discussion

A huge zone of diapiric serpentinite seamounts along the trench axis in the Izu-Bonin and Mariana forearcs suggests that the mantle wedge peridotites just above the subducting slab are pervasively serpentinized by water supplied from the pelagic sediments at the top of the subducting plate. Whether the diapiric rise takes place or not probably depends on the state of the stress field in the forearc. Tanner

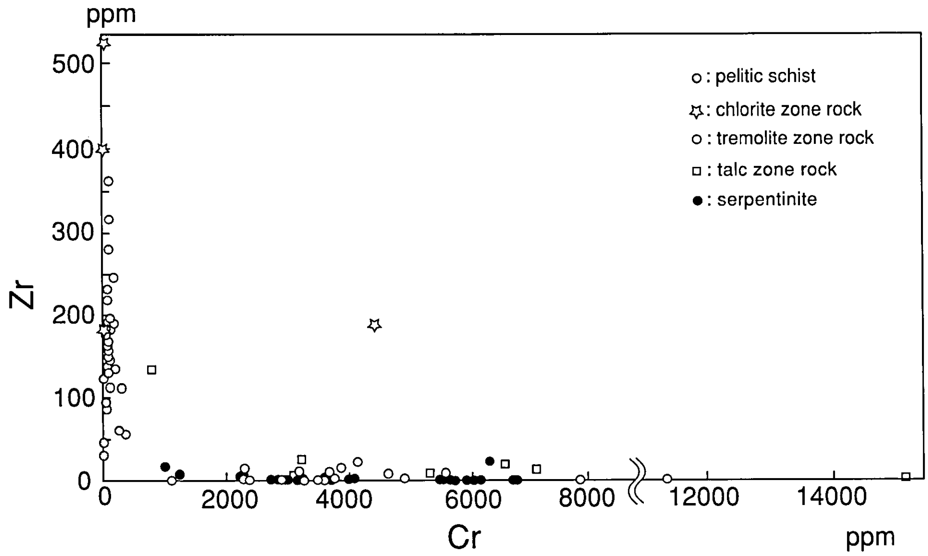

Fig. 5. Zr-Cr diagram of pelitic schists, serpentinites, and their metasomatic derivatives in the Sanbagawa metamorphic belt. Zr contents in pelitic schists depend on the amount of zircon, and Cr contents in serpentinites depend on the amount of spinel.

and Williams (1968) carried out model experiments using asphalt to study relationships between diapirism and regional stress. They concluded that asphalt ridges and domes can only be produced by diapir under the extensional stress field. Taking the tectonic environment of Izu-Bonin and Mariana forearcs into account, the formation of up-rising serpentinite is considered to favor a tensional stress field.

A geochemical study of the 778A rocks suggests that the rocks have a chemical affinity with mid-ocean ridge basalts. Some 778A rocks have zigzag REE patterns due to intense interaction with seawater (Yamamoto *et al.*, 1995). The change in motion of the Pacific plate at Eocene time initiated subduction at a transform fault in the West Philippine Basin (Uyeda and Ben-Avraham, 1972). At the same time, arc volcanism started by the residual high mantle temperatures and initial dehydration of the subducted oceanic crust caused melting at depths of about 50 km at a minimum distance of 50-60 km from the trench axis (Bloomer, 1983). The region of active volcanism has migrated gradually to the west due to the cooling of the mantle wedge by subducting slab. As a result, a part of the oceanic crust of the West Philippine Basin was trapped in the area between the trench and the volcanic front. We inferred that the 778A MORB-type rocks have been supplied from the trapped oceanic crust. Another possibility is that the 778A rocks were derived from the oceanic crust that had been accreted during subduction. Johnson *et al.* (1991) obtained 87-70 Ma K-Ar ages for the MORB-type metabasalts dredged at the Mariana forearc. They inferred that these originated from the Cretaceous oceanic crust that accreted to the Mariana forearc, because on the basis of he crustal ages of the West Philippine Basin the age of oceanic plate that could have been trapped to form the forearc is younger than 56 Ma (Hilde and Lee, 1984). The trapped or accreted oceanic crust may have been tectonically eroded by the subducting slab and dragged into the depths, where blueschist facies metamorphism has taken place.

Most of the Hole 778A metabasalts contain many quartz veins, which have been produced prior to or during blueschist facies metamorphism, because high-pressure minerals, lawsonite, pumpellyite, and aragonite were often crystallized in the vein (Fig. 4 A). The SiO_2-rich fluids which crystallized quartz seem to occur with difficulty under such SiO_2-poor MORB compositions of host rock. When the protoliths of 778A metabasalts have been squeezed deep down by the subducting slab, they have encountered pelagic sediments at the top of the subducting slab. It is reasonable to consider that the SiO_2-rich fluids obtained from the Hole 778A rocks were derived from pelagic sediments on top of the subducting slab.

The clast recovered from Hole 779B(125-779B-01 R-06, 19-22) is a metamorphic clast of possible pelite origin that has not been previously found in the circum-Pacific forearc regions. When the oceanic plate starts to subduct below the other plate, the descending oceanic slab must encounter hanging-wall mantle peridotites at depth. The Hole 779B clast had been the pelagic sediments at the top of the subducting slab that supplied water to peridotites and underwent a metasomatic reaction with peridotites during high-pressure metamorphism.

Based on the seismic reflection-refraction study, Takahashi *et al.* (1998) has shown that the upper mantle velocity beneath the forearc gradually decreases towards the trench axis to become indiscernible from the velocity of the lower crust in the Izu-Bonin subduction system. The unusually low velocity (=7.1 km/s) of the upper mantle beneath the east side of the forearc suggests that a large amount of water is released from the subducting slab and utilized for the serpentinization of the mantle peridotites. They strongly suggested that the root of the serpentinite diapir on the inner trench wall is a low-velocity mantle wedge, which was probably caused by water released from the subducting Pacific plate at depths shallower than 30 km. Shimamoto (1985 and 1993) discussed the seismicity and deformation mechanisms in subduction zones and divided a subduction plate boundary into the three zones: shallow, intermediate, and deep interfaces. He ascribed the aseismic and decoupled natures of the shallow interface to the existence of an enormous amount of water. The shallow interface corresponds well to the low-velocity mantle wedge. The low-velocity wedge at the western side of the trench may coincide with the path of the serpentinite diapir. The low electric resistance at the boundary between the arc and the subducting plate is due to a high water content, and the region corresponds to the low-velocity mantle wedge (Toh, 1993). The Izu-Bonin and Mariana forearc regions were intensively destroyed by many faults caused by tensional stress (e.g. Fryer *et al.*, 1985). Faulting of the forearc to a great depth may make it easy for mantle materials to rise up to the seafloor; that is, voluminous and gravitationally unstable low-density mantle materials generated just above the subducting slab have uplifted along the faults to form serpentinite seamounts on the ocean floor. No serpentinite seamount has developed in the forearc area of the Tonga trench. This may be ascribed to the fact that no fault has developed and the forearc has not been destroyed in the area.

5. Concluding remarks

Since Eocene time, the Pacific Plate has been subducting along the Mariana Trench below the Philippine Sea Plate (Uyeda and Ben-Avraham, 1972). Serpentinite materials, which came up from depths to the seafloor, must have trapped oceanic mantle and crust material situated within the pathway, and entrained them in a fluidized melange rising to the seafloor. Thus, it is reasonable to say that the blueschist-facies clasts recovered from Hole 778A were formed at about 16 to 20 km below the seafloor, and were then entrained by uprising fluidized serpentinite materials. Fig. 6 shows the tectonic framework in the Mariana subduction system explaining how and where the Hole 778A and 779B rocks were formed. The Hole 778A metabasalts were derived from trapped or accreted oceanic crust, which have been eroded by descending slab and have undergone chemical changes due to interaction with seawater. Abundant quartz veins in the Hole 778A rocks suggest that the source of SiO_2-rich fluids, such as siliceous pelagic sediments, was beneath the fragmented oceanic crusts during high-pressure blueschist facies metamorphism (Fig. 6). These rocks may have been far from mantle wedge serpentinites, because no evidence showing metasomatic reaction with serpentinite can be found. The phengite-rich clast of 779B has assemblages formed at multiple stages. The earlier metasomatic mineral assemblages are inferred to have been hornblende + phengite ± rutile. The inferred earlier assemblages and high degree of recrystallization of minerals suggest that the clast was originally formed at the higher temperature, deeper portion in the subduction zone. The protolith of Hole 779B clast is equivocal, but is probably pelitic rock. The Hole 779B clast was formed just below the low-velocity mantle wedge at the western side of the trench, where the rocks are in contact with serpentinite (Fig. 6). The serpentinite diapir initiated at 30-25 km depth, and must have trapped mantle and crust materials situated on the pathway and entrained them in fault gouge and fluids rising to the seafloor.

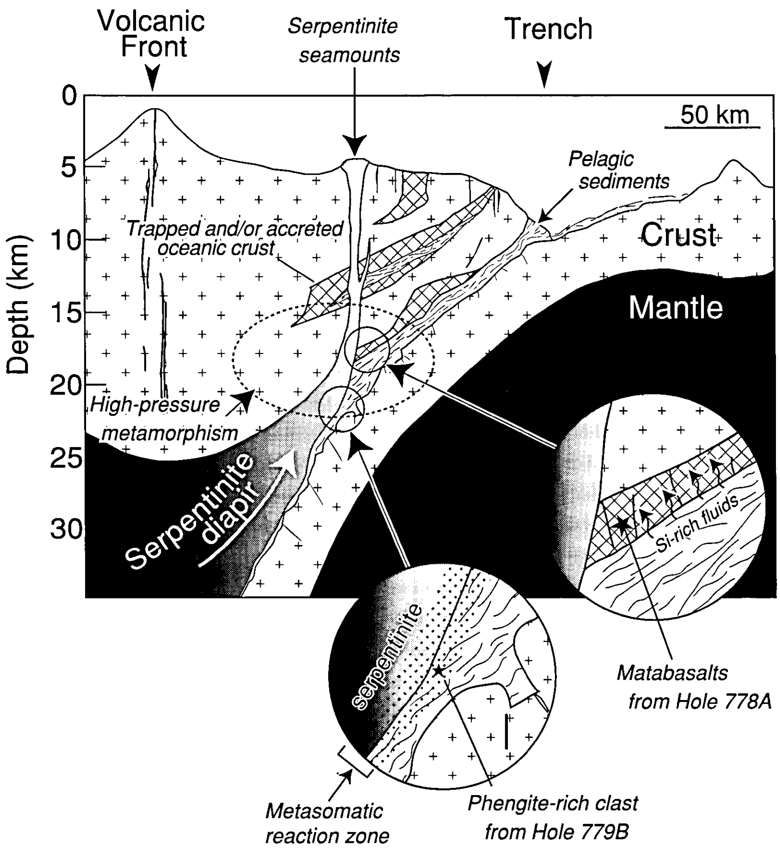

Fig. 6. Schematic cross-section showing the tectonic framework of the Mariana arc-trench system. Serpentinite diapir may continue to serpentinized wedge mantle at a depth of 30-25 km. It must contain trapped clastic and xenolithic fragments originally situated on the pathway of diapir and entrain them in a fault gouge rising to the seafloor.

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伊豆―小笠原，マリアナ前弧域における蛇紋岩海山群と含水マントルウエッジ

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要　旨

近年，環太平洋前弧域では，沈み込むスラブから供給される水により，深さ 15-30 km においてマントルウェッジ・カンラン岩の大規模な蛇紋岩化が発生していることが明らかにされてきた．伊豆―小笠原，マリアナ前弧域において海溝軸に沿って発達する巨大なダイアピル蛇紋岩海山群は，沈み込むスラブ直上に発達した重力的に不安定な低密度の蛇紋岩が上昇し，海底に蛇紋岩海山を形成したことを示している．国際掘削計画第 125 節において，蛇紋岩海山の一つであるコニカル海山の掘削孔 778A と 779B から回収された変成岩片は，前弧物質と水との相互作用に関する重大な情報を与えてくれる．778A の変成玄武岩類は，その地球化学的特徴が中央海嶺玄武岩に類似しており，その中には海水の影響を強く受けた希土類元素存在度パターンを示すものがある．これらは，太平洋プレートの沈み込み開始時に，マリアナ前弧域に封じ込められた海洋地殻あるいは直接付加した太平洋プレートの断片である可能性が強い．封じ込められたあるいは付加した海洋地殻は，スラブの沈み込みにより高圧変成作用が発生している深所まで引きずり込まれたと考えられる．778A の変成玄武岩には通常石英脈が認められる．この石英脈には，ローソナイト，パンペリー石，アラレ石などの高圧鉱物が再結晶していることから，脈形成の時期は変成作用時，あるいはそれ以前であることがわかる．スラブの沈み込みにより削剥・破砕され断片化した海洋地殻は，沈み込むスラブ直上の泥質堆積物に接触する．778A の岩石類に浸透するシリカに富んだ流体は，おそらく，この泥質堆積物に由来するであろう．779B から回収された唯一の変成岩である雲母に富んだ岩片は，超塩基性の組成をもつが，Zr や Ti などの不適合元素に富み Cr や Ni などの適合元素に乏しい．同様の岩石が，三波川変成帯の蛇紋岩と泥質片岩の境界部に発達する反応帯に認められことから，この岩片は，交代作用が普遍的に起こりうるマントルウェッジと沈み込むスラブとの境界部で形成された可能性が高い．