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**Investigation of oceanic lithosphere using tectonic window in backarc
setting: drilling the world's largest Godzilla Mullion oceanic core complex**

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Abstract

OCCs provide a valuable opportunity to directly study the architecture of oceanic lithosphere, together with the tectono-magmatic processes that were associated with its formation and evolution. We have submitted an IODP Full proposal to drill the Godzilla Mullion OCC in the Parece Vela backarc basin in the Philippine Sea (IODP Full-640) to address the major questions in the ocean lithosphere community. It has long been envisioned that the following major questions regarding the mid-ocean ridge processes at various spreading rates can only be best addressed by drilling at tectonic windows such as OCCs:

- (1) lithospheric architecture
- (2) mantle dynamics and melt migration at spreading ridges
- (3) fluid circulation in oceanic lithosphere
- (4) mantle physical properties in serpentinizing lower crust.

However, any models for oceanic lithosphere still need to be understood in terms of a full range of spreading rates, whereby extremely little is known about the architecture of intermediate-spreading ridges. Our proposal for drilling the intermediate-spreading Godzilla Mullion OCC will thus provide a necessary bridge in spreading rates between slow and fast sites. Furthermore, backarc basins are not in some way “anomalous” but are in fact generating a significant fraction of the total oceanic crust. For this reason, the opportunity to explore the formation of the backarc basin lower crust is an important contribution to the overall geology of the ocean basins.

1. Introduction

Exploring the lateral heterogeneity of oceanic lithosphere is one of the primary objectives defined by the current IODP Initial Science Plan. Oceanic core complexes (OCCs) are domal bathymetric highs interpreted as portions of the lower crust and/or upper mantle exposed via low-angle detachment faulting (Cann et al. 1997). These highs are marked by prominent axis-normal striations (corrugations) and often called as “megamullions” (e.g., Tucholke et al., 1998). Godzilla Mullion in the Philippine Sea is by far the largest OCC yet discovered on the sea floor (Ohara et al., 2001).

OCCs provide a valuable opportunity to directly study the architecture of oceanic lithosphere, together with the tectono-magmatic processes that were associated with its formation and

evolution. We therefore have submitted an IODP Full proposal to drill the Godzilla Mullion OCC (IODP Full 640) to address the major questions in the ocean lithosphere community.

2. Background: Godzilla Mullion

The Godzilla Mullion is the world's largest megamullion structure in an extinct Parece Vela backarc basin in the Philippine Sea (Fig. 1). The Izu-Bonin-Mariana (IBM) system in the Philippine Sea is the iconic arc-backarc system. The Parece Vela Basin is a major part of this system, exemplifying backarc crustal construction.

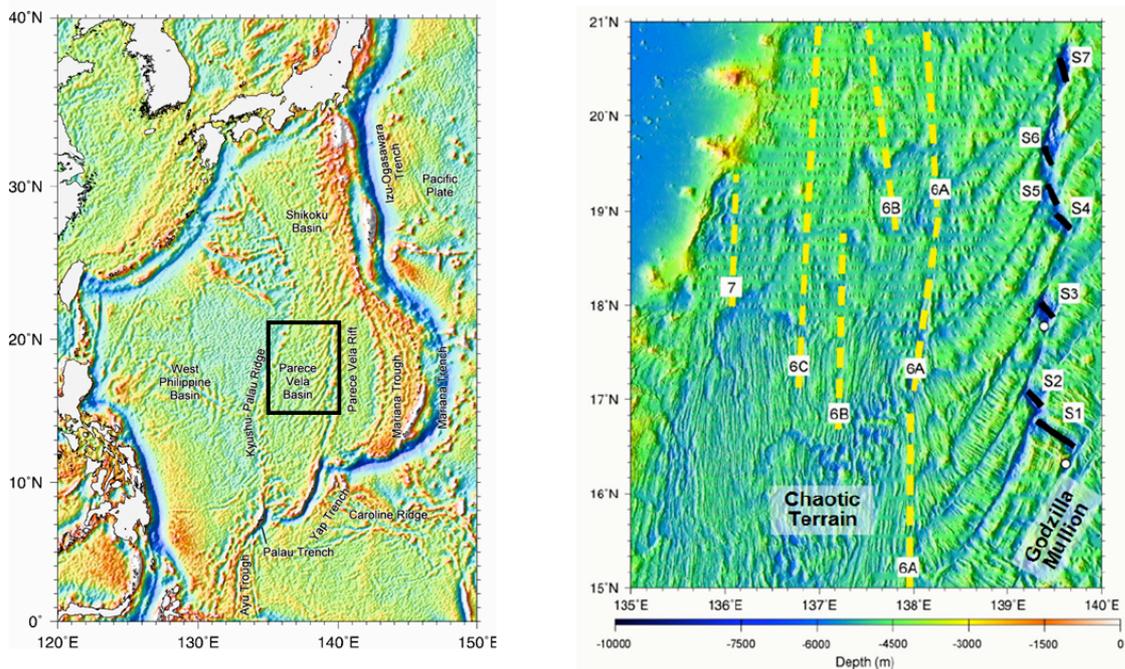


Fig. 1. Index map of the Philippine Sea and the bathymetry of the Parece Vela Basin. Yellow dashed lines in the right panel are magnetic anomaly isochrons. The first order segments of the Parece Vela Rift are labeled S1 to S7 by Ohara et al. (2001). Godzilla Mullion occurs on S1.

Parece Vela Basin spreading consisted of two stages (Okino et al. 1998, 1999), the first of which was E-W rifting and spreading (spreading axes trending N-S) beginning at 26 Ma (4.4 cm/y half-rate; Okino et al. (1998, 1999)). The second stage involved counter-clockwise rotation of spreading axes from a N-S trend to NW-SE at 19 Ma (3.5 cm/y half-rate; Ohara et al. (2001)). Short length first-order segments thus aligned en-echelon with closely-spaced fracture zones, making a zigzag appearance of rift axis (= Parece Vela Rift). This final stage of rifting continued for ~ 9 million years, ending ~ 12 Ma with a ridge jump to the east, and the initiation of the Mariana Trough since ~6 Ma to the present. The spreading appears to

have halted abruptly, leaving the rift “frozen in time”.

Oceanic Core Complexes occur both in the first and second stage of the basin spreading (Ohara et al. 2001). The off-axis Chaotic Terrain consists of multiple OCCs and associated deeps (Fig. 2), similar to the topography of the Basin and Range region in the western US. The last phase of the Parece Vela Rift spreading is unique in that the world’s largest OCC, Godzilla Mullion, occurs here at an intermediate-fast spreading rate (Fig. 2).

Godzilla Mullion is enormous, with approximate dimension $\sim 125 \text{ km} \times \sim 55 \text{ km}$ (Fig. 3), being about the size of the US State of Delaware, which is almost three times as large as the metropolis of Tokyo. More than 16 expeditions were conducted for the study of Godzilla Mullion as of summer 2009, including dredging and submersible diving expeditions and seismic survey cruises. Several lines of evidence from these numerous expeditions indicate a large mantle component of the Godzilla Mullion footwall in both regions. First, demonstrable mantle peridotites occur in nearly every region of the mullion. Second, they are generally affected by crystal plastic deformation to produce porphyroclastic textures typical of abyssal peridotites everywhere, but are not extensively mylonitized to talc-serpentine schists typical of detachment surfaces. This suggests that significant rooted mantle peridotite is exposed along the mullion surface, and that the Moho in these regions is primarily a serpentinization front.

3. Geology of oceanic core complexes

It was initially thought that oceanic detachments rooted primarily on the base of the lithosphere, and thus exposed the crust/mantle transition in many places. This was supported by seismic results suggesting that mantle P-wave velocities were to be encountered within a few hundred meters of the surface (Collins et al., 2001, AGU Abstract). In the meantime, three well-characterized OCCs have been drilled: Hole 735B at the Atlantis Bank at the Southwest Indian Ridge (ODP Legs 118/176/179), ODP Site 1275 at $15^{\circ}45' \text{N}$ in the Atlantic (ODP Leg 209), and IODP Hole U1309D at the Atlantis Massif (IODP Expeditions 304/305). In each case, thick sequences of gabbro have been drilled, with little or no mantle component (Ildefonse et al., 2007). One explanation for this apparent discrepancy between dredging and drilling results is that serpentinite lubricates fault surfaces, localizing strain in the detachment

faults, while the core of OCCs is mostly made of gabbroic rocks (Escartin et al., 1997; Ildefonse et al., 2007). Another part of the puzzle is offered by the ubiquitous interrelation of magmatism, deformation and metamorphism observed in the footwalls of OCCs. Some authors suggest that the magmatic supply is the key to OCC formation (Ildefonse et al., 2007; Tucholke et al., 2008). Numerical modeling suggests that intrusive activity further weakens the root zones of detachments, and fixes the level of both the detachment root and the intrusive zone over long periods of time when the ratio of magma supply to new intrusion is correct (Tucholke et al., 2008). This might be termed the “Goldilocks hypothesis”, i.e., that in order to enable long-lived slip on a detachment fault surface the magma supply should be neither too low or too high, but instead “just right”.

4. Major questions in the oceanic lithosphere community that can be best tested by scientific drilling

The following major questions (which are intimately relating to each other) regarding the mid-ocean ridge processes at various spreading rates can only be best addressed by drilling at tectonic windows such as OCCs:

- (1) lithospheric architecture
- (2) mantle dynamics and melt migration at spreading ridges
- (3) fluid circulation in oceanic lithosphere
- (4) mantle physical properties in serpentinizing lower crust.

5. Our research focus and expected new outcomes

5-1. Architecture and evolution of intermediate spreading lithosphere

Numerous studies including previous ODP Legs (109, 118, 147, 153, 176, 206, and 209) revealed substantial spreading rate (slow or fast) dependent signatures for the architecture and composition of oceanic lithosphere. However, any models for oceanic lithosphere still need to be understood in terms of a full range of spreading rates, whereby extremely little is known about the architecture of intermediate-spreading ridges. Our proposal for drilling the intermediate-spreading Godzilla Mullion OCC will thus provide a necessary bridge in spreading rates between slow (ODP Legs 109, 118, 153, 176 and 209) and fast sites (ODP Legs 147 and 206).

5-2. Architecture and evolution of backarc lithosphere and ophiolites

A significant fraction of the ocean floor is created in backarc basins. The opportunity to explore the formation of the backarc basin lower crust is therefore an important contribution to the overall geology of the ocean basins. At the same time, much of our understanding of all ocean crust comes from ophiolites, most of which are thought to have at least some arc/backarc component (e.g., Dewey and Bird, 1971; Miyashiro, 1973; Pearce, 2003). A better understanding of the construction of backarc basin crust will thus greatly aid in the interpretation of the results of analog studies of ophiolites, and their relevance to the construction of the oceanic crust. Specific questions related to this theme are:

- How does melt generation differ in the backarc environment?
- How is mantle/melt interaction different from normal ocean basins?
- How is the fluid circulation different from normal ocean basins?
- How do peridotite physical properties evolve in serpentinizing lower crust?
- How does the lower crust of a backarc basin compare to observations in ophiolites?

6. The path to achieving our goals

More than 16 expeditions were conducted for the study of Godzilla Mullion as of summer 2009, including dredging and submersible diving expeditions and seismic survey cruises. Based on these expedition results, our plan to drill the Godzilla Mullion is to place the several offset holes on a single detachment surface forming a mullion structure (i.e., a dome) shallower than 4000 m water depth and to use the DV Chikyu to obtain long intact section of the backarc lithosphere.

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