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Key Points:
- Slab pull can pass through the fossil young spreading centers and active intra-arc rifts, but not active spreading centers
- Extremely strong slabs or strong subduction-interface coupling are not needed to explain the IBM trench advance
- The Mariana Trench advance may be driven by the advance of the Izu-Bonin Trench at its north

Supporting Information:

Supporting Information may be found in the online version of this article.

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Slab Pull Drives IBM Trench Advance Despite the Weakened Philippine Sea Plate

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Abstract The mechanism behind the significant Izu-Bonin-Mariana (IBM) trench advance is still controversial. We conduct slab subduction numerical models that reproduce the spatio-temporal tectonic evolution of the Philippine Sea region to investigate whether slab pull from the Ryukyu subduction zone can cross the weakened Philippine Sea Plate and act on the IBM trench. Model results show that the lithospheric strengthening and weakening effects cancel out each other during the rift stage so that the slab pull from the Ryukyu Trench can transmit through the weak fossil spreading centers and intra-arc rifts and drive the Izu-Bonin Trench's advance. In contrast, lithospheric weakening overwhelms lithospheric strengthening and impedes stress transfer in the back-arc spreading stage, suggesting that the slab pull cannot directly pull the Mariana Trench to advance at present. Our study indicates that extreme rheological parameters are not needed for the IBM trench advance, despite the Philippine Sea Plate is weakened.

Plain Language Summary Understanding why IBM (Izu-Bonin-Mariana) has the globe's most significant trench advance affects not only our understanding of subduction dynamics and lithospheric deformation mechanisms, but also our knowledge on slab rheology, which is key to understanding many fundamental geodynamic questions. A number of models have been proposed to explain the IBM trench advance. These models can be broadly classified into two categories: one is single-slab subduction, and the other is double-slab subduction. Single-slab subduction models usually require extreme rheological parameters that seem inconsistent with those inferred from slab curvature and gravity observations, while double-slab subduction models need to consider whether the slab-pull force can transmit through the weak Philippine Sea Plate. The Philippine Sea Plate is strongly weakened due to extensive back-arc extensional deformations. We conduct numerical models that reproduce the first-order tectonic evolution of the IBM Subduction Zone to solve this dispute. The model results show that slab pull from the Ryukyu Trench can pass through the weakened Philippine Sea Plate and act on the IBM Trench. Thus, the IBM Trench advance does not require special rheological parameters as suggested by single-slab models.

1. Introduction

Subduction is usually accompanied by trench advance or retreat (Heuret & Lallemand, 2005). Regardless of the choice of reference frame, the Izu-Bonin-Mariana (IBM) Trench (Figure 1), which is formed by the subduction of the Pacific Plate beneath the Philippine Sea Plate since ∼52 Ma (Ishizuka et al., 2011), has the most significant trench advance on Earth at present (Schellart et al., 2008). Regional plate reconstructions based on paleomagnetic and drilling data, Pacific-Eurasia-Philippine Sea plates triple junction motion, as well as the spatiotemporal evolution of the subducted slab from tomographic imaging, collectively suggest that the IBM trench was initially retreating and then underwent a dramatic shift to advance after ∼8–5 Ma (Carlson & Mortera-Gutiérrez, 1990; Faccenna et al., 2018; Miller et al., 2006; Table S1 in Supporting Information S1).

Understanding the mechanism of the IBM's significant trench advance affects not only our understanding of subduction dynamics and lithospheric deformation mechanisms, but also our knowledge on slab rheology, which is key to understanding various fundamental geodynamic problems (Di Giuseppe et al., 2008; Funiciello et al., 2008). Previous studies suggest that continued trench advance (over several million years) may require very strong slabs whose viscosity is at least 1.5–10 times higher (Ribe, 2010; Stegman et al., 2010) than those constrained by gravity data and compiled global slab curvature (Funiciello et al., 2008; B. Wu et al., 2008; Yang & Gurnis, 2016).

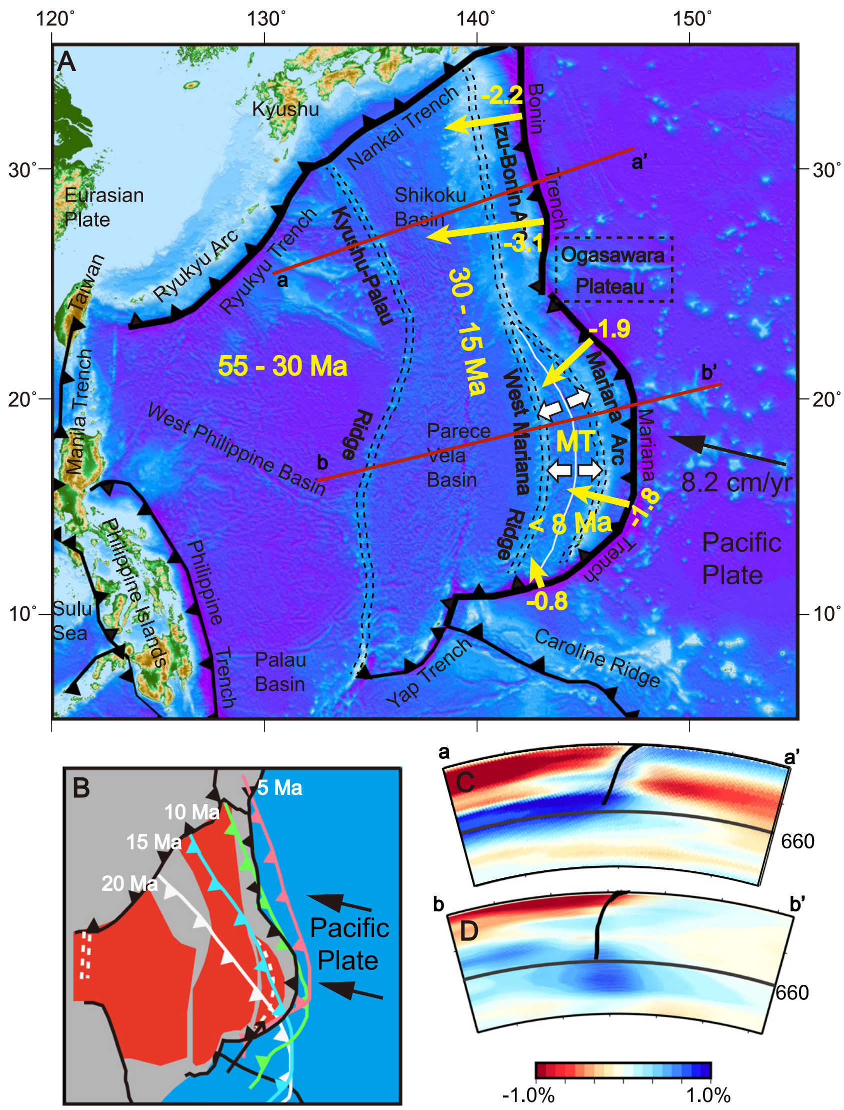

Figure 1. Simplified tectonic maps of the Izu-Bonin-Mariana (IBM) Trench and surrounding areas. (a) Present tectonic features around the Philippine Sea plate. Toothed thick black lines represent trenches. Double dashed black lines represent the present and relics of the IBM volcanic arc. Yellow arrows and numbers next to them indicate the direction and speed (cm/yr) of the IBM Trench's motion, respectively (Schellart et al., 2008). Izu-Bonin (northern segment of the IBM) is rifting while Mariana (southern segment of the IBM) is spreading at present. Yellow numbers followed by "Ma" indicate the time spans of spreading for the Western Philippine Sea Plate, the Shikoku and Parece-Vela Basins, and the Mariana Trough. (b) Schematic evolution of the IBM Trench migration (modified from Faccenna et al., 2018). (c) and (d) P-wave tomographic images of aa' and bb' profiles shown in panel (a) (Fukao & Obayashi, 2013). The black lines represent slab geometry from the slab2 model (Hayes et al., 2018).

On the other hand, the slab-pull force from the Ryukyu Trench due to the Philippine Sea Plate subducting beneath Eurasia can also qualitatively explain the IBM trench's retreat-advance transition since ~8 Ma (Faccenna et al., 2018). However, it is unclear if the weak back-arc regions within the Philippine Sea Plate can be strong enough to transfer the slab-pull force. The inactive Shikoku and Parece-Vela Basin spreading centers were less than 10 million years old when the double subduction system began at 15–5 Ma (Faccenna et al., 2018; Underwood & Pickering, 2018; Tatsumi et al., 2003; Nakada & Kamata, 1991; Table S2 in Supporting Information S1). The Mariana Trough (MT) rifted since ~8 Ma and has became an active spreading center since ~5 Ma (Figure 1; Yamazaki et al., 2003), while the Izu-Bonin back-arc region has been rifting since ~2.5 Ma, forming many back-arc rifts (Ishizuka et al., 2003).

Previous studies (Holt et al., 2018; Čížková & Bina, 2015) suggested that the slab-pull force cannot pass through the Philippine Sea Plate when the back-arc region is too weak. However, it remains difficult to tell whether the

10.1029/2023GL106554

rifting volcanic arc and the young, inactive spreading centers are weak or strong in terms of slab pull transfer without careful examination using sophisticated geodynamic models. These models need to explicitly consider the episodic overriding plate stretching deformations that are consistent with regional tectonics and the nonlinear rheologies that are key in lithospheric faulting and breakup processes (Burov, 2011). Čížková and Bina (2015) pioneered in explaining the IBM Trench advance with double subduction models, but their hypothesis that Ryukyu slab buckling-induced IBM episodic trench motion is not supported by recent tomography studies (Fukao et al., 2009; Fukao & Obayashi, 2013) or regional plate reconstructions (Faccenna et al., 2018). Holt et al. (2018) pioneered in investigating double subduction systems and IBM Trench motion in 3D geodynamic models, but the simple linear rheologies used limited their ability to consider the detailed episodic back-arc stretching events that are key to understanding slab pull transfer across the Philippine Sea Plate. Thus, it is still debated whether slab-pull from the Ryukyu subduction zone can pass through the weakened Philippine Sea Plate and act on the IBM Trench, and whether strong slabs or subduction interfaces (Baitsch-Ghirardello et al., 2014; Ribe, 2010; Stegman et al., 2010) are required to explain the IBM Trench migration. Furthermore, it is unclear whether the along-trench variation of slab morphology in the mantle transition zone, with the Pacific slab stagnating beneath the Izu-Bonin segment while folding and penetrating into the lower mantle beneath the Marianan segment (Figures 1c and 1d), affects slab pull transmission across the Philippine Sea Plate.

In this study, we try to solve the above issues with 2D double-slab subduction models in which the back-arc rifting and spreading centers are self-consistently generated under tectonic stress. After fitting a series of observations, such as the episodic back-arc rifting and spreading events on the Philippine Sea Plate, the Pacific slab morphology, and the IBM trench's retreat-advance transition, we discuss if and how the slab-pull force from the Ryukyu subduction zone can drive the IBM trench to advance.

2. Method

2.1. Model Setup

We demonstrate 15 high-resolution 2D incompressible mantle convection models (Table S3 in Supporting Information S1) that are tailored to simulate the Pacific-Philippine Sea-Eurasia double subduction systems since the late Oligocene (30–25 Ma) and then investigate the effects of back-arc deformation on slab pull transmission from the Ryukyu Trench to the IBM Trench. The lithosphere is divided into three plates (Figure 2a): the oceanic plate 1 (OP1), the oceanic plate 2 (OP2), and the continent plate (CP), representing the Pacific, Philippine Sea, and Eurasian plates, respectively. Subduction of OP1 beneath OP2 models the subduction of the Pacific Plate beneath the Philippine Sea Plate at the Izu-Bonin-Mariana Trench, while subduction of OP2 beneath CP models the Philippine Sea Plate subduction beneath Eurasia at the Ryukyu trench (Figure 1).

The OP1 subduction has already started at the beginning of the model by inserting the slab to an initial depth of 200 km, while the OP2 subduction beneath CP is not initiated until 15 Myr. Regional plate reconstructions indicate that the present Philippine Sea Plate subduction beneath Ryukyu initiated only several million years ago (Faccenna et al., 2018; G. Kimura et al., 2018; Ma et al., 2019), and regional seismological investigations demonstrated that the subducted Philippine slab beneath the Ryukyu has only reached a depth of 400 km (Lallemand et al., 2001; Wei et al., 2012).

Visco-plastic rheology that depends on temperature, pressure, strain rate, and deformation history is used to simulate the complex tectonic deformation and mantle convection in the subduction system. The detailed model settings are similar to those of Yang et al. (2020) and are described in Supporting Information S1. The physical parameters used in this study are listed in Table S4 in Supporting Information S1. The models are constructed and solved with the mantle convection software Underworld2 (Moresi et al., 2007).

2.2. Hot Volcanic Arc

The dehydration of the subducting slab facilitates the melting of the asthenosphere above the slab and the formation of magmatism, which further percolates and intrudes the overriding lithosphere and forms the volcanic arc. The volcanic arc has a high heat flux and geotherm and is thus weaker than the surrounding lithosphere. As a result, almost all back-arc rifting and spreading events in the western Pacific marginal seas originated at the volcanic arc (Tamaki, 1985; Taylor & Karner, 1983).

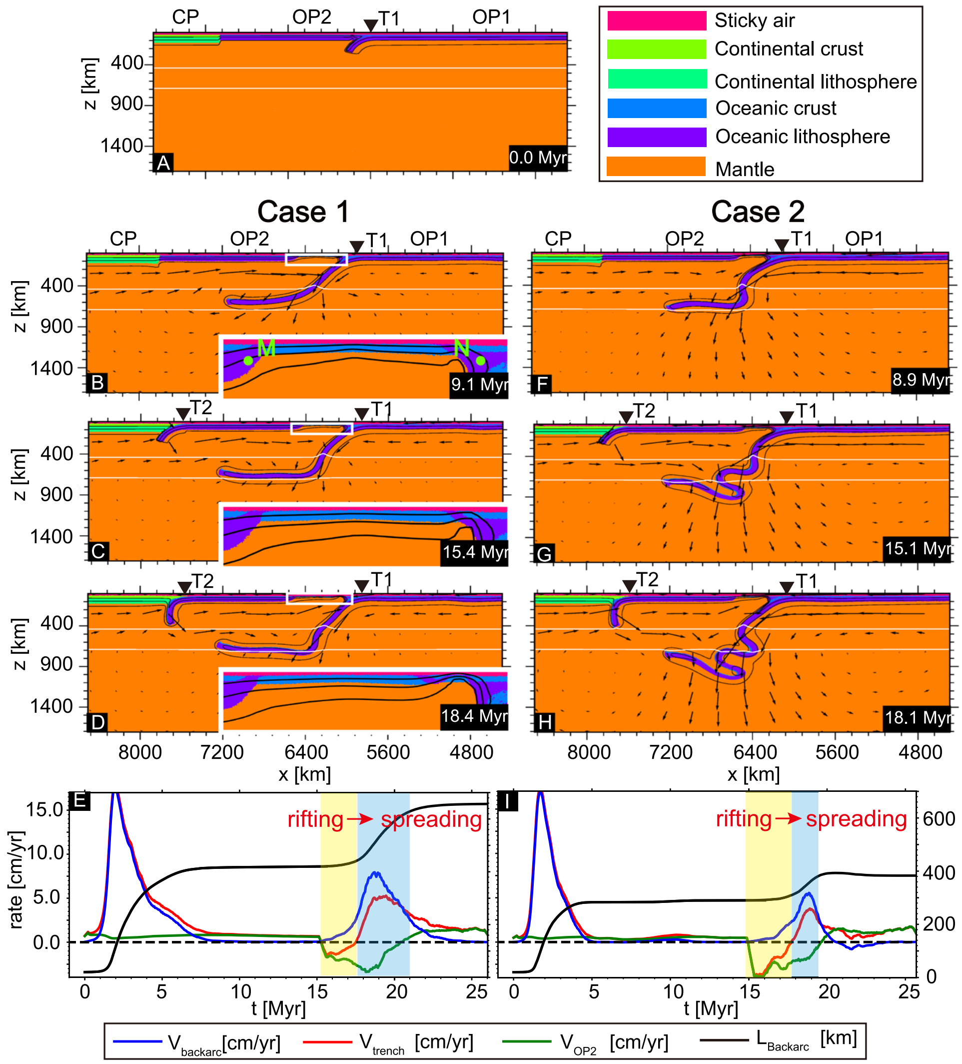

Figure 2. Initial model setup (a) and model evolution of Case 1 (b)–(e) and Case 2 (f)–(i). White boxes in panels (b)–(d) show zoomed-in views of the volcanic arc region. Isotherms of 405°C, 810°C, and 1,215°C are plotted as black curves to demonstrate the thermal structure of the slab and lithosphere. In (e), (i), L_{Backarc} represents width of the highly stretched back-arc region, as measured by the distance between two points M, N (panel b) that were initially located on either side of the volcanic arc. V_{Backarc}, V_{trench}, V_{OP2} represent the velocities of back-arc stretching, trench motion, and oceanic plate 2 motion (at point M, panel b), respectively. The trench motion rate is positive for retreat while negative for advance. We divide back-arc extension into two stages, rifting and spreading, using the stretching velocity of 2.5 cm/yr. This velocity is lower than the current maximum stretching velocity of the Mariana Trough (~4.5 cm/yr; Kato et al., 2003) and higher than the Izu-Bonin intra-arc rifting velocity (<1.0 cm/yr; Nishimura, 2011).

We consider the volcanic arc weakening, which is a key factor influencing the episodic rifting and spreading events on the Philippine Sea Plate. We locate the arc at each time step with its center above the surface of a subducting slab 120 km deep, as suggested by geological observations (Tatsumi, 1986). The hot volcanic arc is set 20 km wide, and we truncate the lithospheric temperature beneath the arc to be higher than that of a 4-Myr-old oceanic lithosphere, whose geotherm is calculated with the half-space cooling model, in the reference models. The effects of the width and equivalent half-space cooling age of the volcanic arc on slab-pull force transfer are investigated (see Section 3.2 and in Supporting Information S1).

3. Results

3.1. Reference Models

We design two cases (Figure 2, Table S3 in Supporting Information S1) with the OP1 plate moving at a rate of 4 cm/yr (Case 1) and 10 cm/yr (Case 2), respectively. This difference in the OP1 plate motion rate reflects the fact that the trench-perpendicular Pacific plate movement in the Izu-Bonin segment is significantly lower than that of the Mariana segment due to the clockwise rotation of the IBM trench in the past 30 million years (Figure 1b; Sdrolias et al., 2004; J. Wu et al., 2016). The Pacific Plate motion rate perpendicular to the Mariana Trench is ∼10 cm/yr at present (Schellart et al., 2008). The comparisons between Case 1 and Case 2 enable us to investigate how variations in subduction dynamics, such as slab morphology, trench motion, back-arc stretching, and other factors, along the IBM trench affect the transmission of slab-pull force across the Philippine Sea plate.

Model evolution of Case 1 is shown in Figures 2b–2e, Figure S1 and Video S1 in Supporting Information S1. In response to the subduction of OP1 beneath OP2, a back-arc basin forms on OP2 (Figure 2b), analog to the formation of the Shikoku Basin on the Philippine Sea plate during 30–15 Ma (Deschamps & Lallemand, 2002; Mahony et al., 2011; Sdrolias et al., 2004). The back-arc spreading peaks at a velocity of 17 cm/yr and averages at 4.4 cm/yr, consistent with the rapid Lau Basin spreading rate at present (16 cm/yr; Taylor et al., 1996) and the 4.0 cm/yr average Shikoku Basin spreading rate suggested by geological investigations (Nishizawa et al., 2011). This rapid back-arc spreading decouples the motion between the trench T1 and OP2 distal from the trench (Figure 2e). The trench T1 retreats fast during this period of back-arc basin spreading, consistent with the fast Izu-Bonin trench retreat in previous regional reconstructions (Faccenna et al., 2018; van der Hilst and Seno, 1993). In response to this fast trench retreat, a stagnant slab forms within the transition zone beneath OP2, similar to seismic observations beneath the Izu-Bonin segment (Figure 1c). When the back-arc spreading rate gradually decreases during 8–15 Myr when a stagnant slab has formed (Yang et al., 2018), the back-arc spreading center cools off and the lithosphere restrengthens, as seen from the deepening of the isotherms beneath the back-arc spreading center (Figures 2b and 2c). The motion of the trench and OP2 are generally coupled during this period (Figure 2e).

The subduction of OP2 beneath the CP is initiated at 15 Myr by inserting OP2 beneath CP to a depth of 200 km (Figure 2c; see Text S3 in Supporting Information S1 for details). In response to this slab subduction, a second-stage back-arc rifting and spreading center develops (Figures 2c and 2d). The stretching center forms above the volcanic arc instead of the weak relicts of the mid-ocean ridge, analogous to the generation of rifts above the Izu-Bonin arc instead of the young relicts of the inactive Shikoku mid-ocean ridge. Driven by the subduction of OP2, the trench T1 begins to advance at ∼15 Myr (Figure 2e). The motion of the trench T1 and plate OP2 are generally coupled, although the back-arc region is suffering slow stretching before 17.5 Myr (Figure 2e). The back-arc deformation is dominated by intra-arc rifting during this period, in which the lithospheric geotherm beneath the volcanic arc changes slowly with time (Figures 3b and 3c) and the lithospheric viscosity is moderate (Figure 3f), allowing the tensile stress to pass through the volcanic arc (Figures 3b and 3c). As the back-arc stretching rate increases and a spreading center forms, the motion of the trench T1 and distal OP2 decouples, and the trench retreats again (Figure 2e). We term this period the spreading period, with the geotherm beneath the volcanic arc high, the lithospheric viscosity two orders lower than that during the rifting period, and the tensile stress unable to pass through the arc (Figure 3). Investigations on the transmission of tectonic force indicate that during the rifting phase, more than 1.25E12 N/m tectonic force (Figure 3g) or 120 MPa tectonic stress (Figure S3 in Supporting Information S1) can pass through the deformation center. However, these values decrease significantly during the stretching phase.

Compared with Case 1, the high OP1 subduction rate in Case 2 makes the slab buckle and penetrate into the lower mantle (Figures 2f–2h). However, many phenomena observed in Case 1, such as the episodic back-arc rifting and spreading events, the transition from trench retreat to trench advance during the slow intra-arc rifting phase after the initiation of OP2 subduction beneath CP, and the decoupling effects of the rapid back-arc spreading on trench motion, are also observed in Case 2.

3.2. Parameter Tests

Geological reconstructions suggest that there may have been a period of Ryukyu subduction during the opening of the Shikoku and Parece Vela basins between 30 and 15 Ma (Malavieille et al., 2002; Seton et al., 2012). We conduct Cases 3–4 (Figure S4 in Supporting Information S1) to investigate how this proposed subduction of the

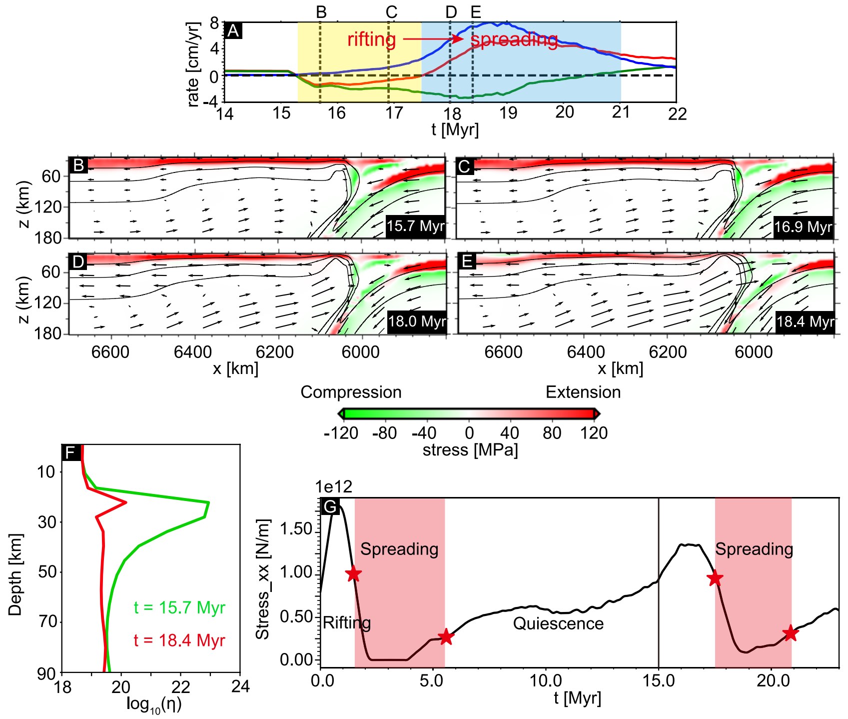

Figure 3. (a) Zoom-in of Figure 2e. The times corresponding to (b)–(e) are indicated by vertical dashed lines. (b)–(e) Horizontal normal stress (red for horizontal extension and green for compression) during the rifting (b), (c) and spreading (d), (e) phases of Case 1. Black curves represent isotherms as in Figure 2. Black arrows represent convection velocity. (f) Viscosity profile beneath the deformation center (rifting center or mid-ocean ridge) during the rifting and spreading phases. (g) Evolution of the tectonic force (integrating τ_{xx} from surface to the lithosphere bottom represented by the 1,215°C isotherm) beneath the deformation center. The vertical line at 15 Myr marks the beginning of OP2 subduction.

Philippine Plate during the Shikoku basin's opening affects the Izu-Bonin trench's motion. Cases 3–4 (Table S3 in Supporting Information S1) differ from Cases 1–2, respectively, in that subduction of OP2 beneath CP initiates at 3.5 Myr when the back-arc spreading center is still active (Figure S4). The significant trench advance observed in Cases 1–2 is not observed in Cases 3–4, suggesting that the cessation of the Shikoku-Parece Vela basin spreading is necessary for slab-pull force transmission and the formation of the significant IBM trench advance, as also suggested by Holt et al. (2018).

We investigated the effects of the motion velocity of OP1 (determined either self-consistently by the mantle convection system or imposed) and the width of the hot volcanic arc on the transfer of slab-pull force (refer to Figure S5 in Supporting Information S1). These investigations demonstrate that the back-arc stretching state controls both the slab-pull force transfer and the motion of trench T1, that is, slab pulling force can transmit through the weak back-arc region and lead to trench advance during the slow rifting phase, while the trench switches to retreat during the rapid back-arc spreading phase.

4. Discussion and Conclusion

Our study reveals that slab-pull force in the double subduction system can transmit through the weak rifting volcanic arc, the weak young fossil back-arc spreading centers, and turn the trench T1 from retreat to advance (Figures 2 and 4a). On the other hand, the back-arc spreading center can effectively hinder the slab-pull force transmission (Figure 4b), consistent with previous inferences (Holt et al., 2018; Čížková & Bina, 2015). These conclusions remain unchanged regardless variations in OP1 subduction histories, OP2 subduction initiation times, or weak volcanic arc widths. This indicates that the back-arc stretching state acts as a first-order control on the trench motion of OP1, and differences in slab morphology and subduction history between the southern (Mariana) and northern (Izu-Bonin) segments of IBM have only minor effects.

The influence of the back-arc stretching state on slab pull force transmission can be explained by the competing effects of lithospheric weakening and strengthening. Nonlinear dislocation and plastic creeps localize the back-arc

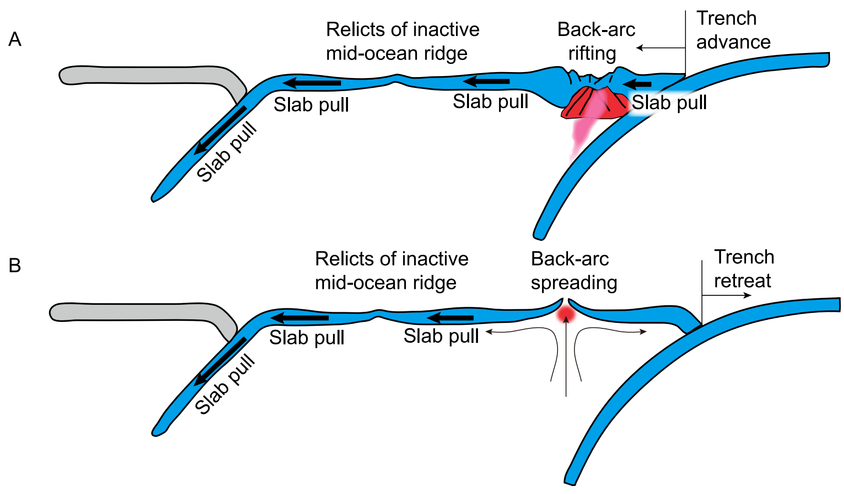

Figure 4. Diagram illustrating the influence of back-arc deformation on slab-pull force transfer in a double-slab subduction system. Slab-pull force can cross young relics of inactive mid-ocean ridges and intra-arc rifts and cause the trench advance (a), but it cannot cross active spreading mid-ocean ridges (b).

deformation in the weakened deformation centers. The lithospheric viscosity decreases with increasing deformation rate. Conversely, thermal diffusion from the lithosphere to the isothermal seafloor cools and strengthens the subarc lithosphere. During slow rifting, lithospheric strengthening can counteract weakening (Naliboff & Buiter, 2015; Van Wijk & Cloetingh, 2002), leaving the lithosphere geotherm and strength largely unchanged. However, during rapid spreading, hot asthenosphere material advects toward rifting and spreading centers, heating and weakening the subarc lithosphere (Figure 3f and Figure S6 in Supporting Information S1). Our models show an exponentially increase in back-arc stretching rate from rifting to spreading, consistent with the competition between lithospheric strengthening and weakening controlled by plastic yielding and strain-rate-dependent rheology (Brune et al., 2016; Christensen, 1992). The nonlinear rheology leads the young Philippine slab beneath Ryukyu to often break off in our models (e.g., Movie S1 in Supporting Information S1). This phenomenon has also been inferred by geological investigations (see Text S4 in Supporting Information S1 for detailed discussions).

Considering that a back-arc spreading center has formed in the MT, with the maximum spreading velocity reaching 4.5 cm/yr (Kato et al., 2003), while the Izu-Bonin segment is still under slow intra-arc rifting (Tanahashi et al., 2008), we suggest that the Izu-Bonin trench advance can be attributed directly to the slab pull force from the Philippine Sea Plate subduction, whereas the Mariana trench advance cannot. This suggestion is supported by geological reconstructions which suggest that the IBM trench did not advance (Faccenna et al., 2018) during 30–15 Ma of Philippine Sea plate subduction that coincides with the period of Shikoku and Parece Vela basins opening (J. I. Kimura et al., 2005; G. Kimura et al., 2014; Seton et al., 2012).

We suggest that the Mariana Trench's advance is at least partially driven by the advancing Izu-Bonin trench, which may be driving the Mariana Trench to move coherently with it. The observations that the Mariana Trench and the Mariana Arc are more than one hundred kilometers eastward of the Izu-Bonin Trench and Arc, respectively (Figure 1a), support our hypothesis. Our hypothesis is also consistent with the observation that, despite the westward motion velocity of the Philippine Sea Plate increasing from north to south (Becker et al., 2015), the Mariana Trench advance rate is slower than that of the Izu-Bonin Trench (Figure 1a; Schellart et al., 2008).

Many seamounts, including the Ogasawara Plateau and the Caroline Ridge, have subducted beneath the IBM Trench (Figure 1a). If the IBM Trench advance is caused by seamount subduction rather than the slab pull of the Ryukyu subduction, the arc region of IBM should be in a compressional state. However, the extensive intra-arc rifting and back-arc spreading events in the past 8–5 Myr suggest that the IBM trench's advance should be attributed to the slab pull from the west rather than the seamounts subduction. Previous studies suggest that a seamount's subduction into a trench can cause the trench to advance or retreat in regions surrounding or further away from the seamount, respectively (Mason et al., 2010; Wallace et al., 2009). However, this model cannot account for the entire IBM's advance. Therefore, we propose that seamount subduction is not the primary driver for the IBM trench's motion.

Slab rheology is key to understanding the driving force for plate motion (Behr et al., 2022; Nakakuki et al., 2008) and subduction zone energy dissipation (Krien & Fleitout, 2008). Our study suggests that the significant advance of the IBM trench can be explained without invoking active trench advances as in one-slab subduction models (Baitsch-Ghirardello et al., 2014; Ribe, 2010; Stegman et al., 2010). Trench advance in the one-slab subduction system may necessitate a slab viscosity significantly higher than that constrained by slab curvature and gravity data (Ribe, 2010). Thus, our study demonstrates that the significant IBM trench advance is consistent with previous studies suggesting that the slab is weak and that some weakening mechanism must exist to weaken the cold slab (Yang & Gurnis, 2016). The weak slab means that most of its gravity potential is consumed to drive mantle convection and plate motion, while only a small portion (less than 20%) is spent to bend the slab at the hinge zone (Krien & Fleitout, 2008).

The Ryukyu subduction initiation is not self-consistently incorporated in our study. We discussed this limitation in Text S3 in Supporting Information S1, and further investigations of the still vague mechanism of Ryukyu subduction initiation will enhance our understanding of regional tectonics. Our study reveals the effects of the episodic back-arc stretching events on the transmission of the Ryukyu slab-pull force across the Philippine Sea Plate and on the IBM trench motion. However, comparisons between 2D and 3D models of IBM trench motion (Faccenna et al., 2018; Holt et al., 2018) and our investigations on the effects of plate subduction velocity on IBM trench migration show that the slab dip angle and the detailed trench motion history (duration, retreat-advance transition time, trench advance velocity) will be affected if along-strike variations in slab subduction history and plate geometry that are consistent with regional observations are considered. We need to analyze variations in slab pull transfer along the trench strike using 3D geodynamic models in the future to further deepen our understanding of the dynamics underlying the significant IBM trench advance.

In conclusion, we show that the slab pull can pass through weak, inactive spreading centers and active rifting volcanic arcs but not active back-arc spreading centers. This distinction in stress transmission is attributed to the competitive effect between lithospheric weakening and strengthening. We suggest that slab pull from the Ryukyu Trench drives the advance of Izu-Bonin (the northern segment of IBM), where the volcanic arc is rifting at present. In contrast, slab pull cannot directly drive the trench advance of Mariana (southern part of IBM), where the MT is actively spreading. The advance of the Mariana Trench may be dragged along by the advance of the Izu-Bonin Trench.

Data Availability Statement

The open-source software underworld2 is used to construct and run the models in this study and is freely available at http://www.underworldcode.org. The tectonic and geophysical data used to plot Figure 1 were derived from published papers: the IBM Trench's motion is from Schellart et al. (2008), the IBM Trench migration history is from Faccenna et al. (2018), the tomographic data is from Fukao and Obayashi (2013), and the slab2 model is from Hayes et al. (2018).

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