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Changbaishan Volcanism: Is Seamount Subduction the Missing Piece?

Xiaobo He*[1], Mingli He[1], Yibing Li[1], Jiashun Hu[2], Fabin Pan[3], Zhensheng Wang[3], Jianshe Lei[4]
1. *Marine Science and Technology College*, *Zhejiang Ocean University*, *Zhoushan* 316022, *China*
2. *Department of Earth and Space Sciences*, *Southern University of Science and Technology*, *Shenzhen* 518055, *China*
3. *State Key Laboratory of Geological Processes and Mineral Resources*, *China University of Geosciences* (*Wuhan*), *Wuhan* 430074, *China*
4. *National Institute of Natural Hazards*, *Ministry of Emergency Management of China*, *Beijing* 100085, *China*

0 INTRODUCTION

Changbaishan volcanism, located on the border of China and North Korea, has been a subject of extensive research due to its unique geological features and active volcanic history (Wan et al., 2024). Two primary models have been proposed to explain the origin of Changbaishan volcanism (CV). (1) Dehydration model (e.g., Lei and Zhao, 2005; Zhao et al., 2004): This model suggests that fluids released from the subducted slab in the mantle transition zone (MTZ) contribute to the formation of magma beneath the volcano. (2) Slab tearing model (e. g., Gao et al., 2025; Tang et al., 2014): This model involves mantle upwelling caused by slab tearing in the MTZ, which leads to the generation of magma. Zhang et al. (2019) further suggested that both dehydration and slab tearing processes perhaps coexist in the MTZ to explain the CV. The existence of slab tearing is supported by multiple lines of direct and indirect evidence. For instance, a low-velocity gap, indicative of a slab tear, has been identified within the stagnant slab beneath Northeast China through 2-D triplicated waveform modeling (Lai et al., 2019). Seismic anisotropy observations further suggest localized mantle upwelling through the slab gap (Han et al., 2024). To fully validate the two models, three key questions must be addressed: (1) What mechanism drives slab tearing? (2) What process governs the slab's water enrichment in the MTZ? This question arises in light of Green et al. (2010), who argue that subducting lithosphere carries negligible water below 400 km depth. Closely tied to this issue is the question of why water enrichment is localized within the slab. (3) What is the relationship between the CV and the clustered deep seismicity in the MTZ. In this study, we present a conceptual model (Figure 1) that invokes the foundering of seamounts or oceanic plateaus within the MTZ, providing a coherent explanation for all the previously raised issues. We elaborate on the explanations of all the issues in the following section.

*Corresponding author: xiaobo.he@zjou.edu.cn

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1 SEAMOUNT FOUNDERING MODEL

1.1 Seamount Foundering Induced Slab Tearing

A key element of our model is the invocation of seamount foundering in the mantle transition zone, which subsequently triggers slab tearing. Slab tearing within the MTZ triggered by seamount foundering can occur due to three key processes:

(1) Seamount-trench interactions: These interactions can generate fractures within seamounts and their surrounding areas (He et al., 2022), creating zones of weakness that become susceptible to tearing during slab-MTZ interactions.

(2) Variations in viscosity and density: Differences in viscosity and density between seamounts and the surrounding slab result in varying negative buoyancy, slab strength and subduction speeds. Consequently, localized deformation occurs along the seamount-slab boundary, potentially facilitating slab tearing.

(3) Crustal thickness and phase transitions: The thicker crust of seamounts contains a higher concentration of basaltic material, promoting the phase transition from majoritic garnet to perovskite (Wang and He, 2020). This transformation plays a crucial role in enabling slab sinking into the lower mantle, thereby contributing to slab tearing. More specifically, seamounts and oceanic plateaus possess a thicker basaltic crust than normal oceanic lithosphere. The persistent accumulation of this thickened basaltic crust facilitates the earlier onset of the phase transition, compared to typical oceanic crust. As a result, while the thinner crust tends to stagnate within the MTZ due to delayed phase transformation, the crust associated with seamounts and oceanic plateaus is more likely to undergo the transition in time and sink into the lower mantle. Additionally, in the context of oceanic plateau subduction, the mantle lithosphere is thicker than that of typical oceanic lithosphere. This condition facilitates accelerated subduction and contributes to plateau foundering.

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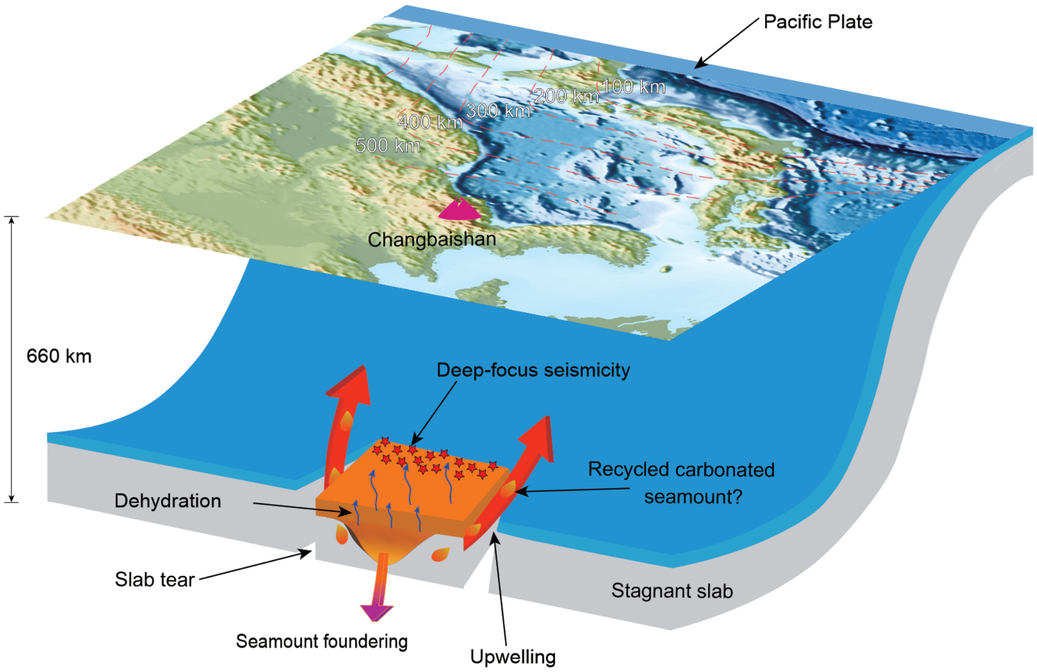

Figure 1. A schematic model illustrating seamount foundering in the mantle transition zone and its cascade effects, including slab tearing, mantle upwelling, seamount dehydration, dehydration-induced seismicity, and the recycling of carbonated seamount material.

As a result, seamount or oceanic plateau foundering in the MTZ readily facilitates slab tearing, triggering mantle upwelling that generates magma to sustain intraplate volcanism.

1.2 Water-Rich Seamount Subduction

The dehydration model, proposed by earlier studies (e.g., Lei and Zhao, 2005; Zhao et al., 2004), requires a substantial influx of water into the MTZ, transported by the subducting slab. This contrasts with Green et al. (2010), who argued that subducting lithosphere carries negligible water below 400 km depth. Furthermore, if the subducting slab can deliver significant amounts of water into the MTZ, we would expect widespread intraplate volcanism associated with slab dehydration at those depths. Consequently, we propose the seamount subduction model, which not only accounts for water enrichment in the MTZ but also explains the localized nature of water concentration within the slab.

Recent studies (e. g., He et al., 2022) support the seamount subduction model, highlighting its critical role in transporting substantial amounts of water into the deep mantle. Chesley et al. (2021) suggest that a subducting seamount delivers 3.2 to 4.7 times more water to the deep mantle compared to normal, unfaulted oceanic lithosphere. This implies that seamount subduction could facilitate a greater influx of water into the MTZ. It has become increasingly evident that nominally anhydrous minerals and dense hydrous magnesium silicates can transport water to depths exceeding 300 km (Wu et al., 2025). However, a precise quantitative estimate of water transport into the MTZ via seamount subduction remains uncertain. The hydration of seamounts primarily occurs through two key processes (He et al., 2022): (1) initial hydration during their formation and (2) faulting-induced hydration resulting from seamount-trench interactions.

Despite its significance, the role of seamounts in delivering water to the MTZ has not received sufficient attention from the Earth sciences community and warrants further investigation. Notably, the dehydration of subducted seamounts in the MTZ can be accelerated by persistent heating from mantle upwelling induced by slab tearing.

Furthermore, the dehydration of water-rich seamounts provides a compelling explanation for the localized deep seismicity in the MTZ—a mechanism widely employed to interpret intermediate-depth seismicity within subducting slabs (e.g., Jung et al., 2004). We will explore this issue in greater detail in the next subsection.

1.3 Deep Clustered Seismicity in the MTZ

It has long been suggested that deep seismicity within a subducting slab can largely be attributed to the phase transformation of metastable olivine (Green et al., 2010). Thermal runaway has also been recognized as a key mechanism explaining earthquake ruptures for large magnitudes (M_w > 6.5) (Zhan et al., 2017). Compared to transformational faulting and thermal runaway, dehydration embrittlement has received less attention as an explanation for deep seismicity, primarily because some studies have argued that the subducting lithosphere carries negligible water below a depth of 400 km (e. g., Green et al., 2010).

Notably, the role of slab dehydration in the genesis of deep seismicity is beginning to gain recognition. For instance, thermal modeling indicates that carbonated crust and hydrated mantle in cold slabs can produce fluids at depths corresponding to deep-focus earthquakes (Shirey et al., 2021). A recent study demonstrated that hydrous minerals (phase A and B) can retain significant water contents down to MTZ depths, and their dehydration may induce deep seismicity (Ishii et al., 2025). If the subducting oceanic crust at depths greater than 300 km contained substantial amounts of water, one would expect a double seismic zone, akin to those observed in intermediate-depth seismic regions. However, the absence of such a feature suggests that any water enrichment within the slab in the MTZ, if present, is likely localized rather than widespread. As a result, localized fluid activity can be employed to explain some clustered deep earthquakes in the MTZ.

Therefore, we propose that the deep clustered seismicity beneath the Changbaishan volcano may be linked to the dehydration of a deep-seated hydrous seamount in the MTZ. This dehydration process is further facilitated by heating due to hot mantle upwelling through the slab tear, as previously discussed. Localized intense deformation induced by slab tearing may also contribute to the occurrence of clustered deep earthquakes (Gao et al., 2025). The connection between dehydration-induced deep seismicity and the CV has been recognized before (e.g., Zhao and Tian, 2013). Note that the current model is primarily applicable to regions where the slab is torn apart. Earthquakes occurring within the MTZ in other tectonic settings may instead result from metastable olivine phase transformations or thermal instabilities.

1.4 Return of Carbonated Seamount to Explain the Petrochemical Nature of the CV

Geochemical isotope analyses indicate significant contributions from altered oceanic crust to the mantle source of the intraplate Changbaishan volcano (Liu et al., 2024; Xing et al., 2024; Chen et al., 2017). Notably, recycled carbonate plays a crucial role in continental intraplate volcanism (Xu et al., 2025). As seamount crust thickness significantly exceeds the carbonate compensation depth, substantial carbonates can be transported into the MTZ through the subduction of carbonated seamounts as we propose here, while their return to the upper mantle may be facilitated by upwelling induced by the tearing of the stagnant slab (Zhou et al., 2025).

2 SUMMARY

In this study, we propose a novel interpretation that links the CV to the foundering of water-rich carbonated seamounts in the MTZ, which in turn triggers slab tearing. This tearing induces mantle upwelling, a process that not only facilitates the return of carbonated seamount material to fuel intraplate volcanism but also heats the overlying seamount, causing dehydration. This dehydration, in turn, acts as a key driver of deep seismicity. Therefore, we propose that the subduction and foundering of seamounts in the MTZ constitute the missing link in fully elucidating the genesis and dynamics of the CV. In the future, more geophysical observations along with numerical modeling will shed light on the role that seamount subduction plays in the generation of intraplate volcanoes and slab deformation in the MTZ.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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