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SMALL VOLCANOES, BIG MYSTERY

In recent years, a group of scientists discovered a new type of underwater volcano that had thus far gone unnoticed due to their small size.



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Petit-spot volcanoes are relatively young and small, forming along fractures at the base of tectonic plates.

These fractures occur as the tectonic plates descend into the Earth's upper mantle, causing the plates to bend and crack, which allows for volcanic eruptions. The magma released during these eruptions originates from the asthenosphere, the uppermost section of the Earth's mantle responsible for driving the movement of tectonic plate

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Volcanoes, the Earth's fiery vents, are inspiring manifestations of its internal turbulence. They unleash immense energy, shaping landscapes and altering ecosystems with their eruptions. From the majestic, snow-capped peaks of stratovolcanoes to the serene, bubbling pools of lava in shield volcanoes, each volcano tells a unique story of geological evolution and the dynamic forces that govern our planet.

Despite their destructive potential, volcanoes also offer fertile ground for life to flourish, showcasing the resilience and adaptability of organisms in the face of adversity. Studying volcanoes not only unveils the intricacies of Earth's inner mechanisms but also provides vital insights into mitigating the risks they pose to human populations and the environment.

Volcanoes can be found in various geological settings around the globe, often clustered along tectonic plate boundaries. One typical location is the Pacific Ring of Fire, a zone encircling the Pacific Ocean, renowned for its intense volcanic activity. Other common areas are the mid-ocean ridges, where tectonic plates spread apart, allowing magma to rise and form underwater volcanoes. Additionally, volcanic hotspots, such as those found in Hawaii and Yellowstone, occur away from plate boundaries, where plumes of hot mantle material breach the Earth's surface, creating chains of volcanic islands or supervolcanic calderas. Lastly, subduction zones, where one tectonic plate sinks beneath another, often host explosive stratovolcanoes like those found in the Andes or the Cascade Range. These diverse locations showcase the dynamic nature of volcanic phenomena across the planet.

Recently, scientists from Japan discovered a new type of volcanoes, known as *petit-spots*, shedding new light on our understanding of intraplate volcanism. Petit-spot volcanoes are small underwater volcanoes, typically standing only a few tens of meters high, erupting along lithospheric fractures in response to oceanic plate flexure during subduction. Their discovery was of great significance, demonstrating that tectonic processes can trigger intraplate volcanism and supporting the existence of small-degree melts at the base of the lithosphere. Shortly after the discovery of *petit-spots*, a debate emerged regarding the wide distribution of these volcanoes over a relatively small area, significantly altering the composition of the sedimentary cover of the incoming oceanic crust.

Moreover, on a larger scale, they impact the chemical cycle of arc magmatism and the global volatile cycle. Therefore, *petit-spots* have a significant impact on the subduction system in terms of megathrust rupture nucleation and slip propagation.

Under an OPUS grant from Poland's National Science Center, our team of researchers (including myself) from the Institute of Geophysics, Polish Academy of Sciences, in collaboration with scientists from Université Grenoble Alpes and the Japan Agency for Marine-Earth Science and Technology, will investigate the influence of *petit-spot* volcanism on the structure of the lithosphere using seismic imaging methods. Our project aims to integrate cutting-edge seismic waveform inversion and imaging techniques with unique seismic data types to generate high-resolution models of the subsurface in the outer-rise region of the Japan Trench – the location where *petit-spot* volcanoes were first discovered 15 years ago. Based on the proposed mechanism of *petit-spot* volcano development, we

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hypothesize that their formation will induce lateral variations in the physical parameters of the oceanic crust and uppermost mantle. As of now, high-resolution crustal-scale inversion and migration methods stand as the sole robust techniques for imaging these variations.

The power of teamwork

The need for more detailed insight into the shallow structure of incoming sediments in this area has already been recognized by an international group of scientists, who recently submitted an ocean drilling proposal aimed at assessing the nature of the sedimentary cover affected by *petit-spot* magmatism. Detailed seismic imaging of these structures will therefore further support the drilling program and provide complementary information about the studied area. Our project aims to obtain a detailed image of the changes in the sedimentary cover caused by *petit-spot* volcanism to understand how they alter the inputs to the subduction zone and how this may affect the geodynamic system during the nucleation and propagation of large and devastating earthquakes.



Further reading:

Hirano N., Takahashi E., Yamamoto J., Abe N., Ingle S.P., Kaneoka I. et al., Volcanism in response to plate flexure, *Science*, 2006.

Hirano N., Machida S., Sumino H., Shimizu K., Tamura A., Morishita T., Iwano H., Sakata S., Ishii T., Arai S., Yoneda S., Danhara T., Hirata T., Petit-spot volcanoes on the oldest portion of the Pacific Plate, In: I. Belkin, I.G. Priede (Ed.), *Deep-Sea Research*, Part I, 2019, doi: 10.1016/j.dsr.2019.103142

Górszczyk A., Operto S., Malinowski M., Toward a robust workflow for deep crustal imaging by FWI of OBS data: The eastern Nankai Trough revisited, *Journal of Geophysical Research: Solid Earth* 2017, doi: 10.1002/2016JB013891

On the other hand, petit-spots are just small-scale surface evidence of the volcanic processes that occur in the deeper lithosphere. These processes are still not fully understood and require further investigation. To address this, our team aims to build high-resolution crustal-scale models of the underlying structures. We intend to recover variations in physical parameters associated with petit-spot volcanism down to the uppermost mantle. These variations should be seismically visible, and their precise reconstruction is a key factor in understanding how lava migrates from the deep lithosphere through the oceanic crust to erupt and form petit-spots.

In the broader perspective, our team of scientists believes that advancing academic regional-scale seismic imaging is imperative to enhance our technical capabilities for reconstructing deep geological targets. They now have a unique opportunity to conduct an important and intriguing feasibility study of high-resolution crustal-scale imaging, simultaneously identifying and addressing bottlenecks for future progress. Leveraging high-quality data, computing power, and technology developed over years, combined with accumulated expertise in the

field, this project is an exceptional chance to engage the geological and geophysical community in leading-edge methodologies.

This initiative aims to stimulate a new generation of seismic data acquisition, encouraging dense sampling of the subsurface and inspiring efficient source code development for extensive utilization of available high-performance computing power. Furthermore, it seeks to foster ongoing research on robust modeling and inversion approaches. By uniting these aspects of next-generation crustal-scale seismic imaging, the project offers an opportunity to build upon the experiences of past decades and accelerate the technical development of crustal-scale seismic imaging. Recognizing that this evolution is a long-term process, involving input from field acquisition engineers, software developers, mathematicians, physicists, and other scientists, the proposal aims to support the emergence of a new generation of young, talented geoscientists. These individuals would play a pivotal role in both academic research laboratories and industrial research and development departments, contributing to environmental understanding and sustainability efforts. ■