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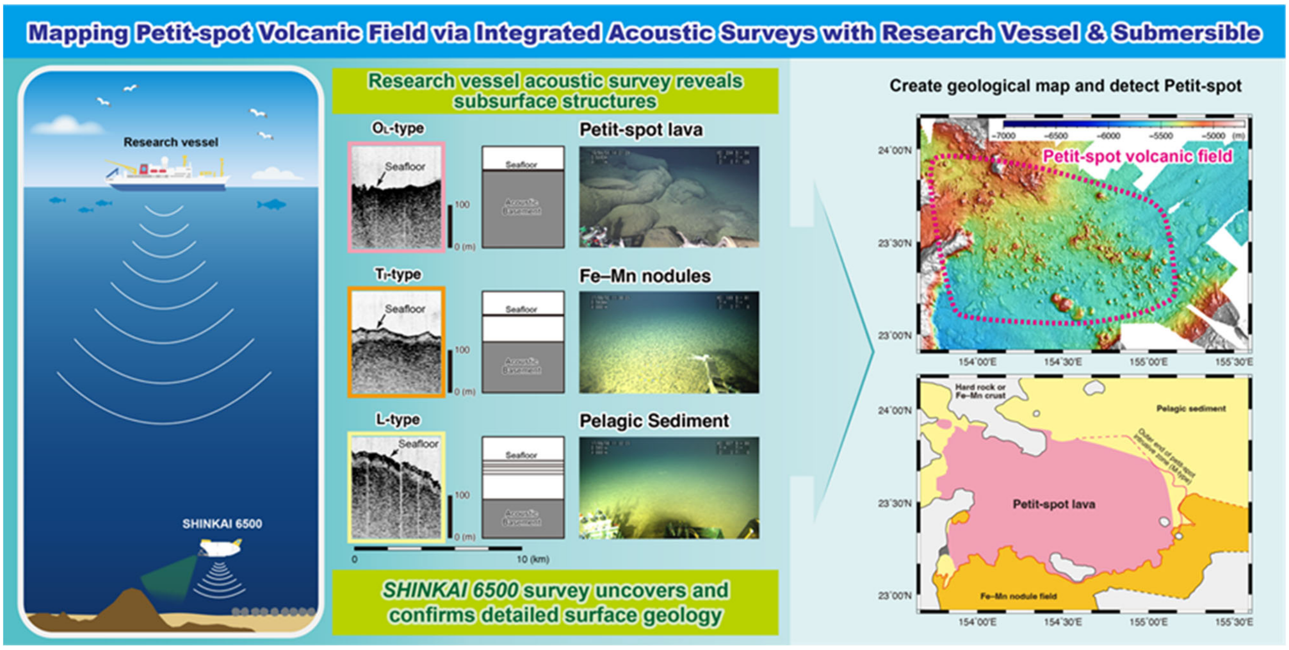
# Mapping Hidden Deep-Sea Petit-Spot Volcanoes

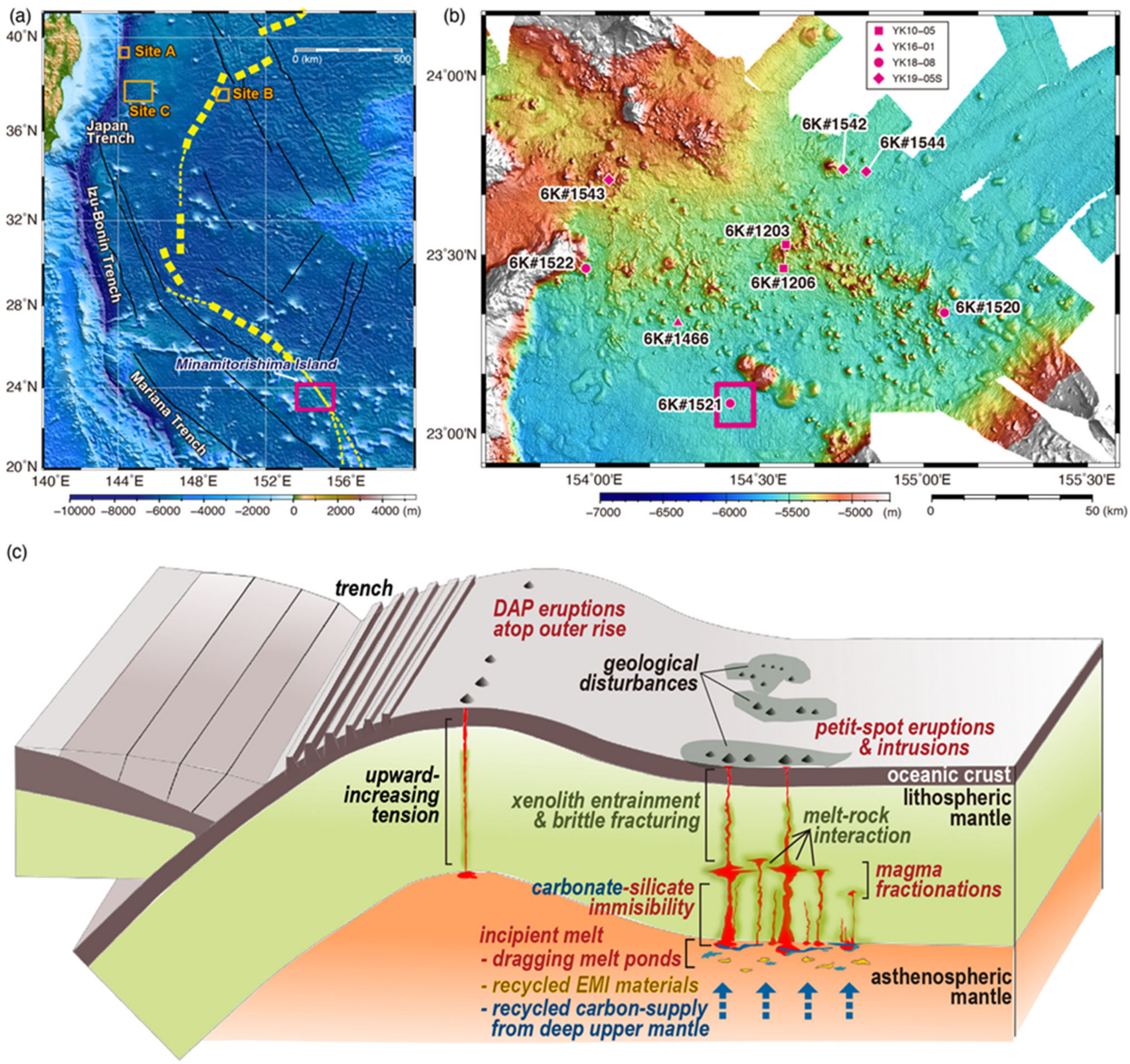
## — A New Era of Seafloor Geological Survey Using Integrated Acoustic Observations from Research Vessels and the *Shinkai 6500* Submersible —




A team led by the Chiba Institute of Technology has developed a novel geological survey method that integrates wide-area acoustic mapping from research vessels with high-resolution acoustic observations via submersible manned *Shinkai 6500*. This integrated approach enables the precise delineation of petit-spot volcanic activity and its spatial extent on the deep seafloor.
The results were published in the journal *Scientific Reports* by Springer Nature.

Petit-spot volcanoes arise when magma from the Earth's mantle interacts with bending oceanic plates, producing small volcanic features that alter the entire thickness of the plate. Since these “metasomatized oceanic plates” eventually subducted into the Earth’s mantle at trenches, understanding the distribution of petit-spot volcanism and its influence on the oceanic plate is crucial for unraveling the mechanisms behind megathrust earthquakes and the global cycling of plate materials within the Earth's interior.

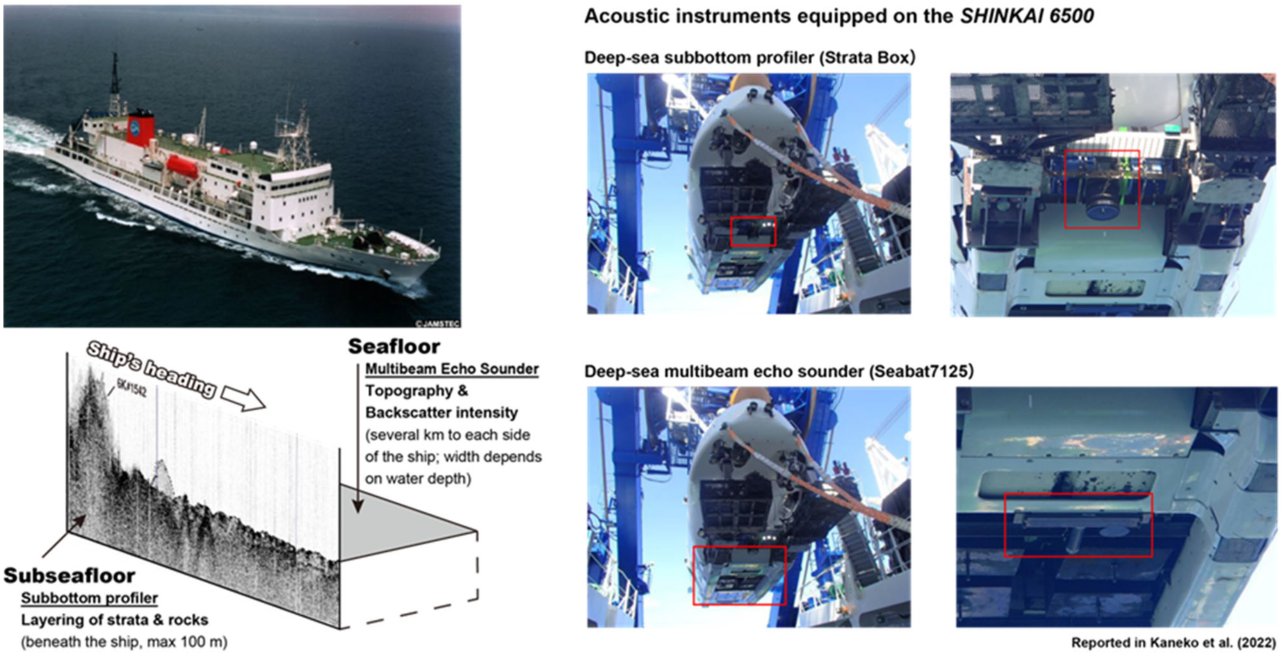
Traditional acoustic surveys using multibeam echo sounders from research vessels typically detect small seafloor mounds interpreted as petit-spot volcanoes. However, previous dives by *Shinkai 6500* revealed petit-spot lavas on flat seafloor areas without obvious mounds visible from vessel-based multibeam echo sounders, suggesting that conventional methods underestimate the extent of volcanic activity. Images from these dives illustrate these subtle volcanic features that had previously gone unnoticed.




**Bathymetric map of the petit-spot volcanic field southeast of Minamitorishima and a conceptual diagram of petit-spot volcanic activity.** In panel (a), the yellow dashed line indicates a structural depression known as the outer rise, where the oceanic plate bends just before subduction—this is where petit-spot volcanism occurs. Panel (b) shows the dive locations of *Shinkai 6500* where petit-spot lava was observed. The conceptual diagram

(c) is adapted from Hirano and Machida (2022).

To address this, the researchers analyzed data from 11 survey cruises conducted between 2013 and 2019 around Minamitorishima Island. These cruises involve not only multibeam observations (for bathymetry and backscatter intensity of the seafloor) but also subbottom profiling to reveal subseafloor structure. Furthermore, Nine *Shinkai 6500* dives equipped with compact deep-sea multibeam and subbottom profilers provided high-resolution views of seafloor and subseafloor features over wide areas exceeding several kilometers. Visualizations of these integrated datasets reveal distinct geological units and volcanic structures on the seafloor and beneath it.

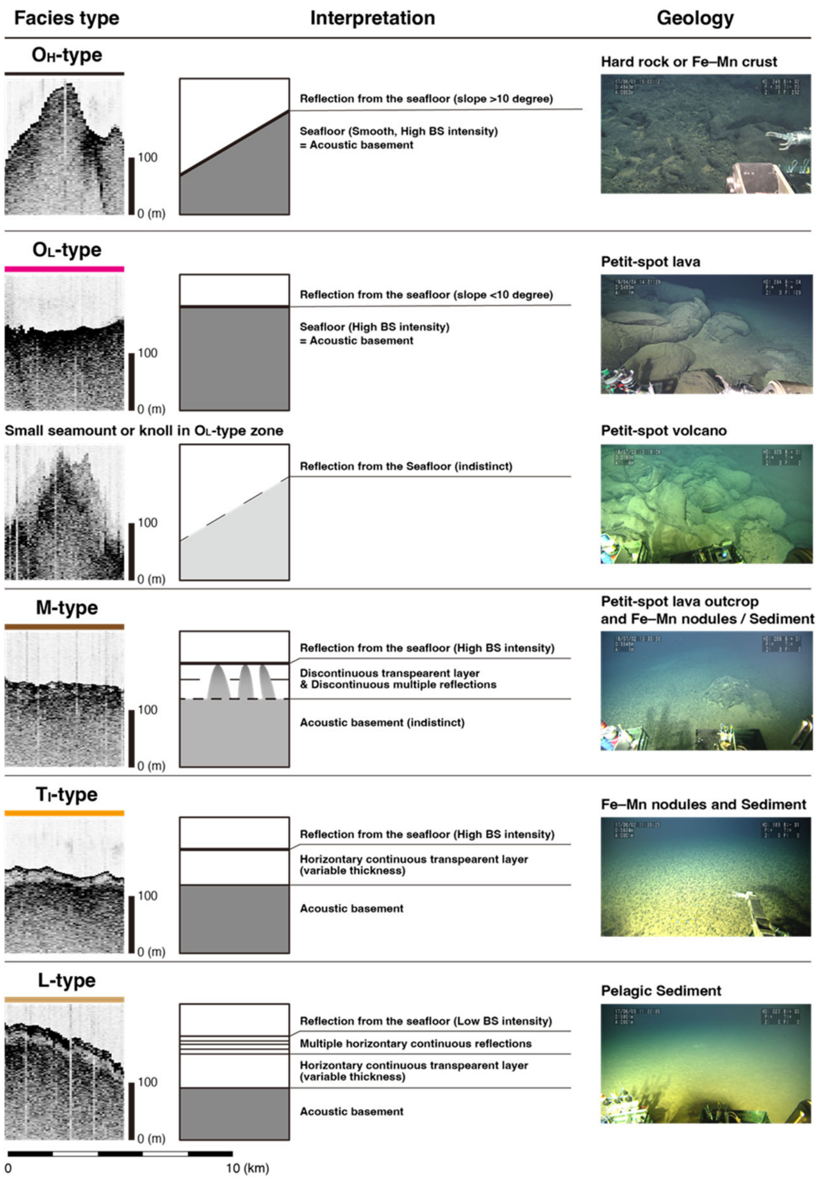



**Overview of the acoustic observations conducted in this study.** A multibeam echo sounder emits fan-shaped pulses of sound waves from beneath a vessel or a submersible. These sound waves reflect off the seafloor and return to the receiver, allowing measurement of both depth (based on the travel time of the sound) and seafloor hardness (based on the intensity of the backscattered signal). As the ship or submersible moves forward, it can continuously scan the seafloor in strips, enabling wide-area mapping in a single pass. However, the width of the area covered depends on the distance between the sensor and the seafloor. High-frequency sound waves provide higher resolution and can capture fine details, but their range is limited—making them ideal for close-range surveys near the seafloor. In contrast, low-frequency waves have lower resolution but can reach greater depths, making them suitable for wide-area mapping from surface vessels. In this study, high-frequency multibeam systems were used on a *Shinkai 6500* for close-up surveys, whereas low-frequency systems were employed on the research vessel to cover broader areas. A subbottom profiler emits low-frequency sound waves vertically beneath the vessel or the submersible to investigate structures below the seafloor. Unlike higher-frequency waves used in multibeam echo sounders, these low-frequency signals can penetrate the seafloor surface and travel through underlying sediment layers. As sound waves encounter boundaries between layers with different physical properties (such as density), they are reflected back to the receiver. By analyzing the depth and strength of these reflections, researchers can determine sediment thickness, layering patterns, and the continuity of geological strata.

The multibeam echo sounder and subbottom profiler mounted on *Shinkai 6500* (deep-sea multibeam and deep-sea subbottom) enabled real-time monitoring of acoustic data during dives, allowing researchers to observe results directly from within the submersible.

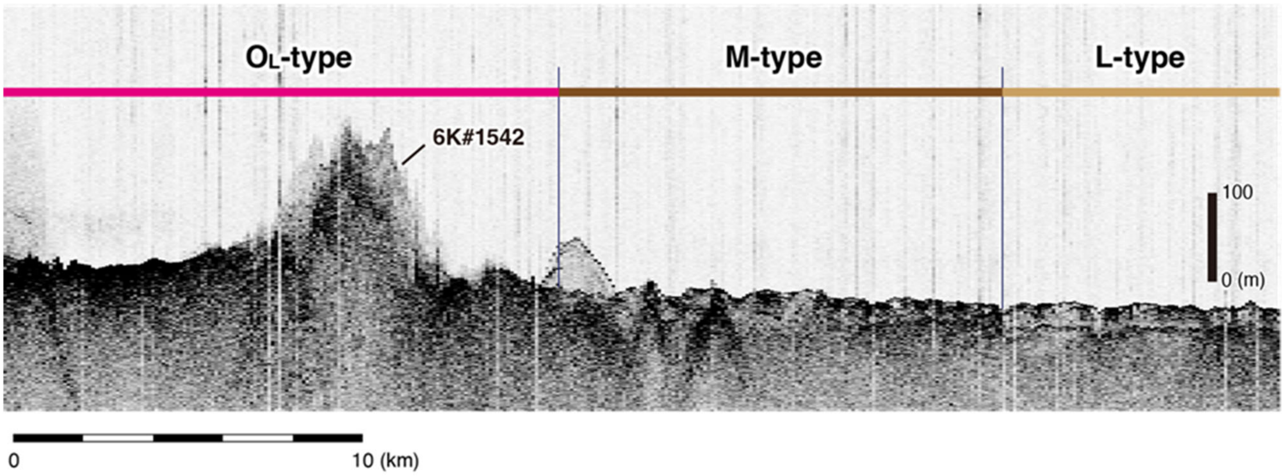
Among the identified subsurface features, an $O_L$-type structure found on flat seafloor was strongly associated with petit-spot lava deposits, serving as a key indicator of volcanic activity. Other subsurface features corresponded to shallow magma intrusions that did not reach the seafloor surface. These features, designated as M-type structure, are illustrated in the accompanying geological diagrams and subbottom profiles.

By combining vessel-based topography and backscatter data with sub-bottom acoustic profiles, the team developed new criteria to reliably identify petit-spot volcanic fields, even in areas where volcanic mounds are not clearly detectable. The comprehensive geological map constructed using these criteria reveals extensive lava distribution across flat seafloor regions previously overlooked by conventional surveys.

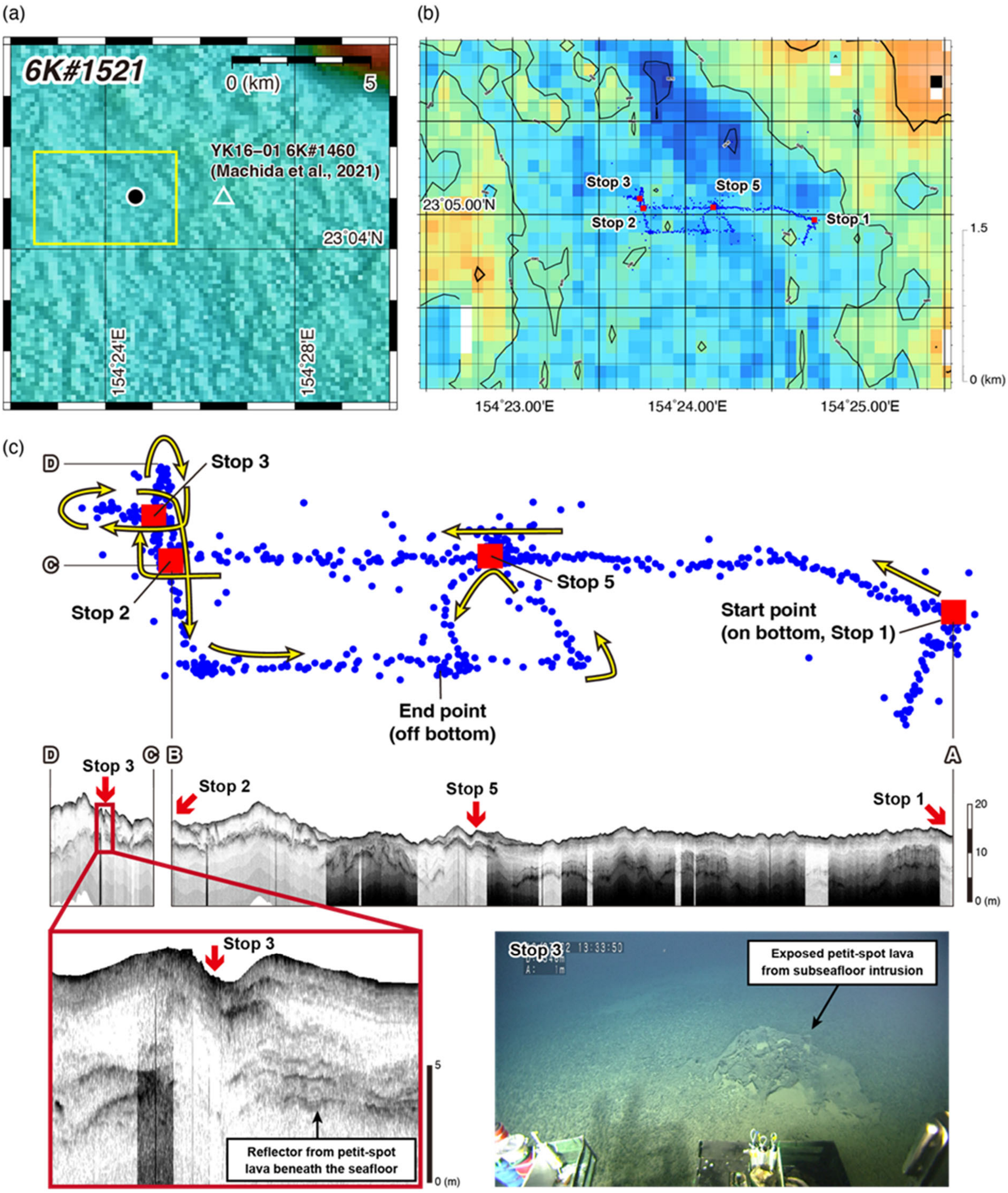


**Subsurface structures identified via vessel-based subbottom profiling and their geological interpretation.** Within the area where OL-type subsurface structures—associated with petit-spot lava—are distributed, numerous small seamounts or knolls have been identified. These features appear with indistinct slopes in vessel-based subbottom profile data, clearly distinguishing them from $O_H$-type slopes, which are typically steep and covered with ferromanganese crusts.

The indistinct appearance of the slopes is likely due to rough surface textures caused by fresh lava flows, which scatter incoming acoustic waves. The presence of such small seamounts with rough, acoustically diffuse slopes serves as further evidence of petit-spot volcanic activity.

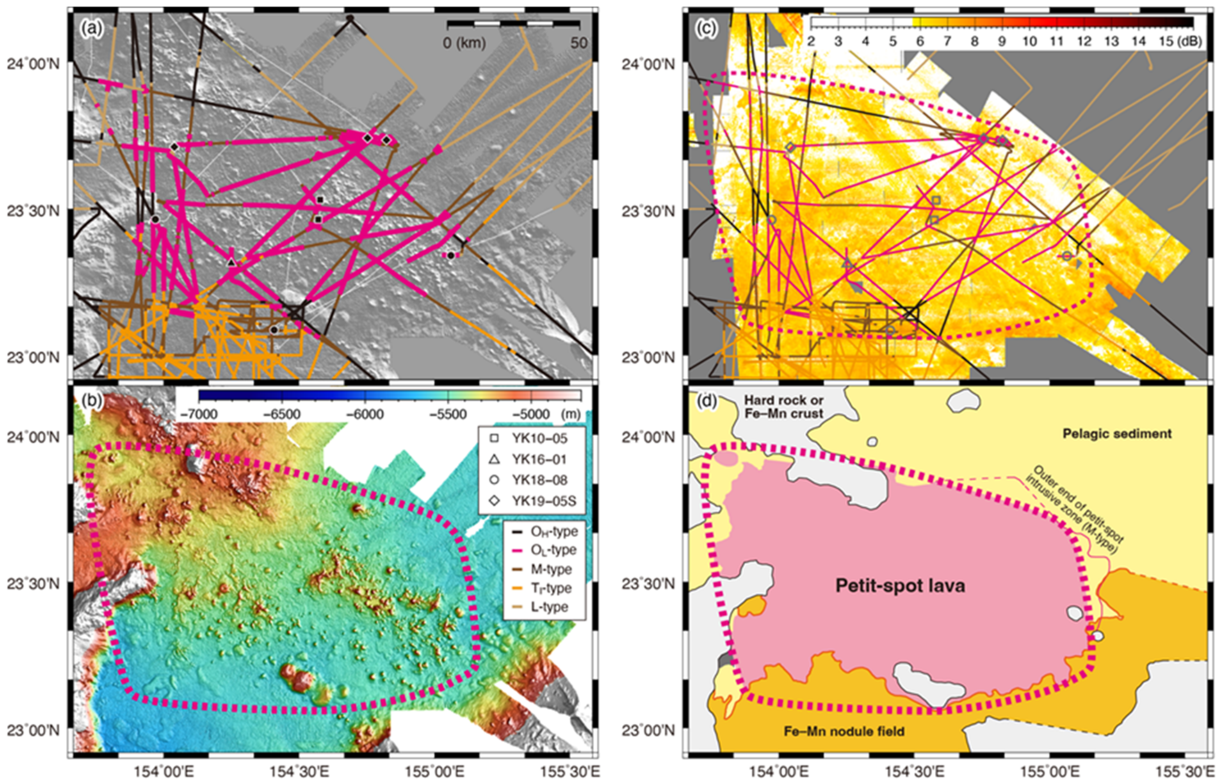



**Subsurface cross-section revealed by the vessel-based subbottom profiler.** This example shows subsurface structures observed near a petit-spot volcano at the *Shinkai 6500* dive site 6K#1542.




**Detailed subsurface observations were performed via a subbottom profiler equipped on a** ***Shinkai 6500*****.** Panels (a) and (b) show the seafloor topography near the *Shinkai 6500* dive site 6K#1521, which was obtained via a vessel-based multibeam echo sounder. The dive area is notably flat and lacks significant seafloor relief, although the bathymetric map in (b) uses color shading to emphasize vertical differences of approximately 100 meters. Panel (c) provides an enlarged view of the dive track shown in (b), along with corresponding subbottom profiling data collected by the deep-sea profiler. Blue dots indicate the position of *Shinkai 6500* at 10-second intervals, and yellow arrows show the direction of movement.

The deep-sea subbottom profiler successfully detected petit-spot lavas intruding into seafloor sediments. A strong reflector, interpreted as petit-spot lava, appears approximately 10 meters below the seafloor at the touchdown point, shallows westward to less than 5 meters near Stop 5, and approaches the surface toward Stop 3. At Stop 3, lava outcrops were observed on the seafloor.




**Summary of integrated acoustic surveys and geological map around the Minamitorishima petit-spot volcanic field.** (a) Results of subsurface structure classification along ship-based subbottom profiler survey lines. Line colors correspond to the structure types shown in the previous figure. White lines indicate areas where no vessel-based subbottom data were available. The color map in the background of panel (c) shows the seafloor backscatter intensity distribution from Machida et al. (2021). Pink dashed lines in panels (b) through (d) outline the extent of the petit-spot volcanic field, as determined by the distributions of $O_L$-type and M-type subsurface structures.

This study represents the first application of an integrated acoustic geological survey method that combines vessel-based and submersible-based observations. "The complementary strengths of wide-area vessel surveys and detailed submersible data provide a cost-effective and accurate means to investigate seafloor volcanic features and related geological processes," said Shiki Machida, a senior research scientist at the Chiba Institute of Technology.

In the future, this method will facilitate a deeper understanding of how petit-spot volcanism modifies oceanic plates and contribute to megathrust earthquake activity, enhancing the knowledge of Earth's tectonic and material cycles. Moreover, this integrated approach is applicable to diverse seafloor geological phenomena, ushering in a new era of marine geoscience exploration.

**Papers**

Shiki Machida, Junji Kaneko, Kazuhiro Inose, Tatsuo Nozaki, Koichi Iijima, Naoto Hirano, “Integrated acoustic identification of a petit-spot volcanic field in the oldest Pacific plate,” *Scientific Reports*: September 9, 2025, doi: 10.1038/s41598-025-15806-y.