

Plate motion is driven by water in the mantle asthenosphere

◆ Key Points

- Seismic wave attenuation characteristics (Q^{-1}), which are indices of the softness of the mantle lithosphere (plate) and asthenosphere, are measured using the short-period oscillation generation technology developed by our research team was successfully determined under high temperature and high pressure.
- It was clarified that the presence of water in mantle rocks increases the attenuation of seismic waves and causes a large decrease in velocity, which could explain seismological observations.
- The fact that the old cold oceanic plate can move smoothly indicates that the asthenosphere contains water.

A research team led by Prof. Takashi Yoshino of the Institute for Planetary Materials, Okayama University, and a joint research group led by Yuji Higo, Senior Researcher of the Japan Synchrotron Radiation Research Institute (JASRI), forcibly vibrate rocks under high-temperature and high-pressure conditions. We succeeded in in-situ observation of the phenomenon of attenuation, in which seismic wave energy is lost. They also revealed that the presence of water in mantle rocks softens the deeper asthenosphere of the mantle, allowing plates (lithospheres) to move more smoothly over it.

The reasons for the asthenosphere softening have not been well understood in plate tectonics theory. , the presence of water in the asthenosphere could explain both the sharp drop in shear wave velocity at the oceanic lithosphere–asthenosphere boundary and the frequency-independent damping in the asthenosphere beneath the old oceanic plate. These research results will be published in the American scientific journal "The Proceedings of the National Academy of Sciences" on 31st July.

■ Announcement contents

<Current situation>

Plate tectonics is a unified theory that explains various activities observed on the Earth's surface, such as mountain building, earthquakes, and volcanic activity. However, the reasons that allow the oceanic lithosphere to move relative to the underlying asthenosphere are still poorly understood. The bottom of the oceanic lithosphere is a hard bedrock layer corresponding to the upper part of the low-velocity layer around 50 to 100 km in depth. , producing a sharp boundary (Fig. 1). Partial melting is a likely cause of geophysical anomalies in the asthenosphere, but it is difficult to explain the abrupt velocity slowdown observed in the cold oceanic upper mantle far from the mid-ocean ridge. Another leading theory is that there is a small amount of water in the asthenosphere, softening the rocks.

However, previous experimental studies that measured the seismic attenuation of olivine, a major

mineral in the upper mantle, reported that the effect of water was not very large. In this previous research, experiments were conducted under conditions of 2,000 atm, which is much lower than the pressure of 20,000 to 30,000 atm, which corresponds to the actual asthenosphere. Therefore, experimental validation at realistic asthenospheric pressures was required.

<Details of research results>

Using beamline BL04B1 of SPring-8, a large-scale synchrotron radiation facility capable of reproducing seismic waves passing through peridotite under conditions of upper mantle pressure equivalent to a depth of approximately 90 km by forced oscillation experiments, and tried the experiment. Combining in-situ synchrotron radiation observation, large-scale high-pressure generator and high-temperature experiments, we have successfully determined attenuation characteristics in a wide frequency range of fine-grained peridotite samples as a function of water content. The experimental results revealed that the damping peak appeared at high frequencies under the hydrated mantle condition, and that the frequency dependence of damping decreased when the asthenosphere contained water (Fig. 2). This makes it possible to explain the difference between the large frequency dependence of the old and cold oceanic lithosphere and the small frequency dependence of the asthenosphere if the lithosphere is anhydrous and the asthenosphere contains water.

The results of this study indicate that the abrupt velocity slowdown and attenuation increase at the oceanic mantle lithosphere-asthenosphere boundary far from the mid-ocean ridge was caused by an abrupt increase in water content across this boundary. (Fig. 3). The mid-ocean ridge basalts of the upper mantle are thought to contain 50-200% by weight of water. It is likely that the oceanic lithosphere completely lost water when it melted during decompression under the mid-ocean ridge at a certain depth (~70 km). Partial melting near the mid-ocean ridge creates a contrast in the amount of water between the lithosphere and asthenosphere, and it is thought that the plate moves smoothly over the boundary.

<Social Significance>

Plate tectonics is a phenomenon that causes earthquakes and volcanoes that can cause enormous disasters for humankind, so it is important to deepen our understanding of it. The results of this study show that the asthenosphere holds a certain amount of water, which is one of the key results for how water is distributed on the earth. It is hoped that this will provide hints for future research.

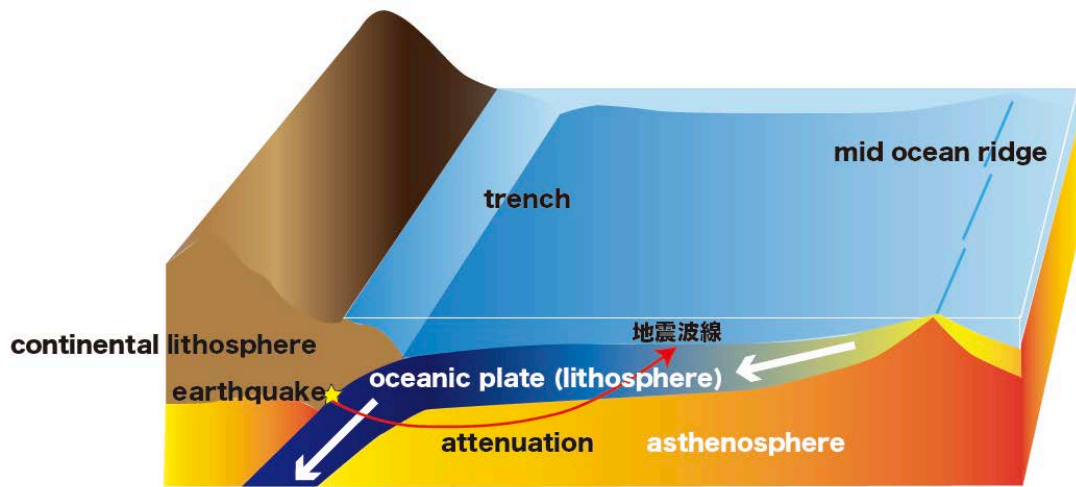


Figure 1 Conceptual diagram showing lithosphere and asthenosphere. Oceanic plates form at mid-ocean ridges and subduct at trenches as they cool.

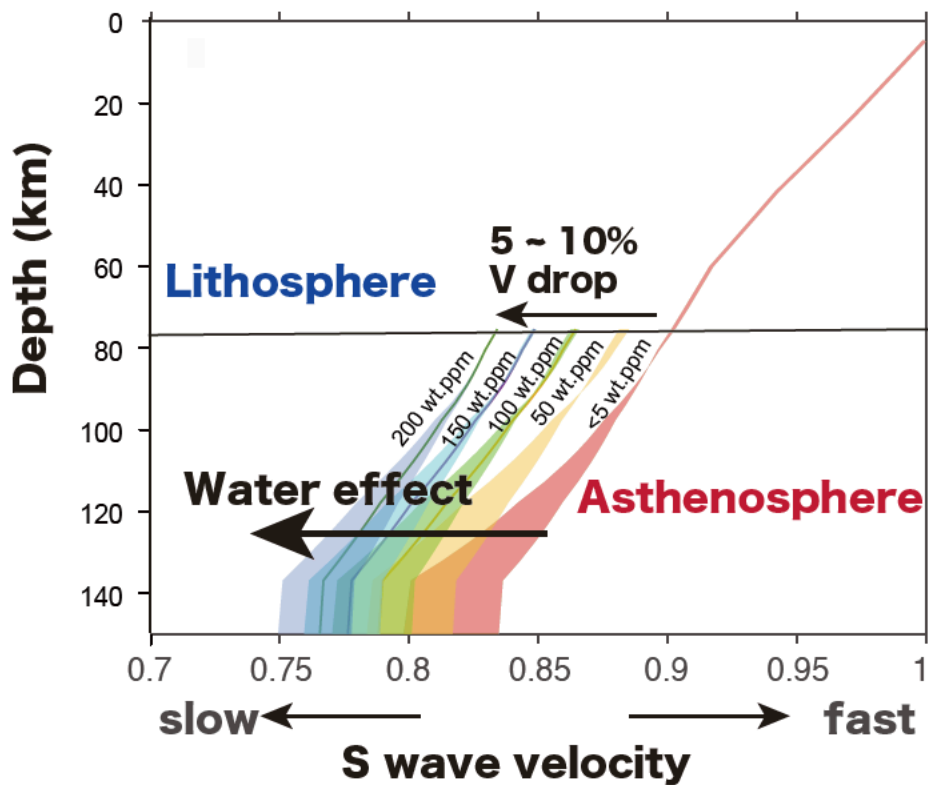


Figure 2 Comparison between the measurement results of this research experiment and the seismic observation results. The difference between the small period dependence of the asthenosphere and the

large period dependence of the lithospheric decay can be explained by the presence of water in the asthenosphere.

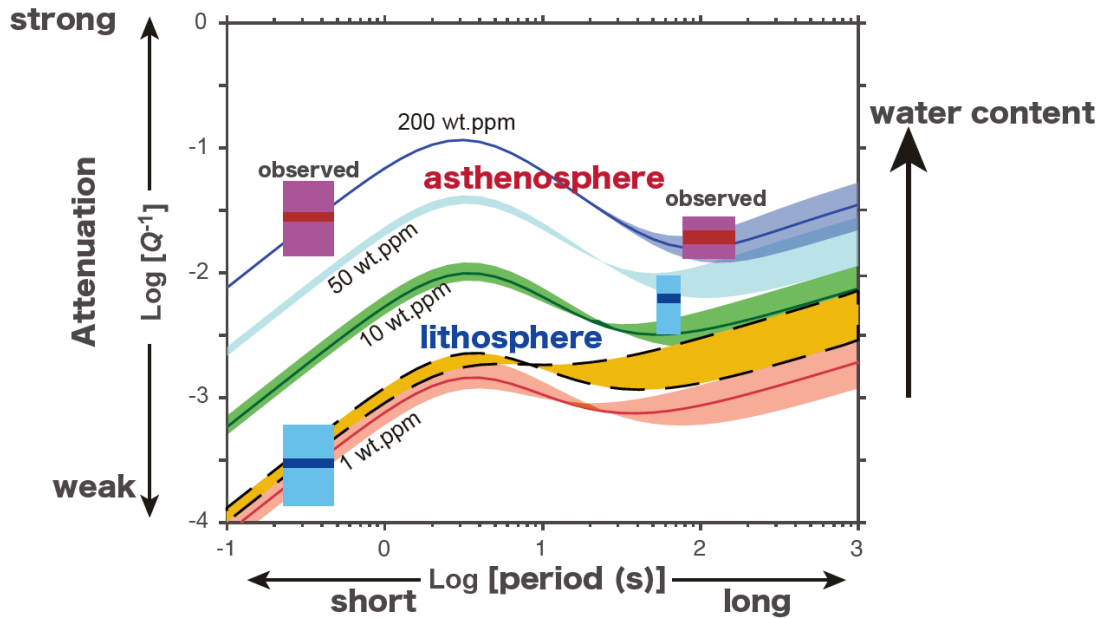


Fig. 3 Profiles of S-wave velocities across the lithosphere and asthenosphere clarified from this study. It can be seen that there is a sharp decrease in velocity when water is present.

■ Paper information

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