Universality of Rock Physics Reveals Internal Structure of the Earth

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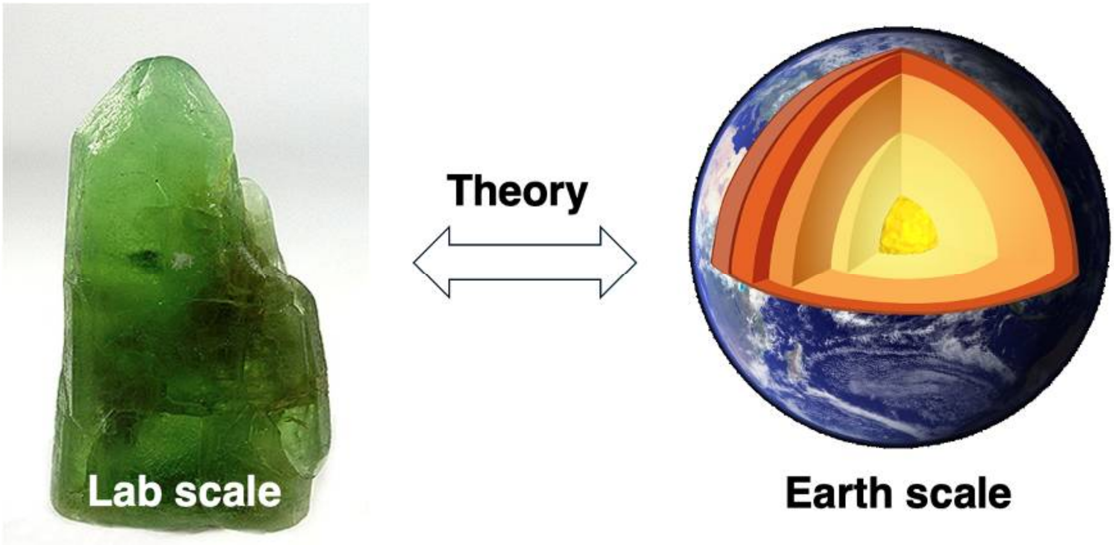


On the 11th of March 2011, major earthquakes and large tsunamis suddenly struck Northern Japan, and at the same time, a nuclear power plant near the epicenter began to melt down. So many people were injured or dead at that time, and a lot of people, including me, had to survive severe conditions outside our hometown for some days, months, or years. So much information flooded TV and the Internet, and some misunderstandings misled vulnerable people. An eight-year-old boy at the time had a simple question: why can we not predict earthquakes for the next day, though we can know the weather for the next week? That question led me to think about the mechanisms behind the natural phenomena we can see on Earth or cannot see inside the Earth.

After I entered junior high school, the physics classes attracted me to think about the natural phenomena in terms of mathematics. For example, using thermodynamics, we can analyze the gas's macroscopic properties, or using classical dynamics, we can predict the target's future position and velocity, even if the target is a planet in the solar system! The assumptions we used in classical physics are so simple, yet we can predict many phenomena from the atomic to the planetary scale.

The earth science classes were found interesting to me, of course, but the "story" told in the class seemed to have less theoretical background and seemed skeptical to me. What is the "slip" between faults that drives earthquakes? How do we know the rough structure inside the Earth? How to interpret the structure in such high resolution that we can see the "slip" between faults? I wonder why people on Earth cannot answer these questions clearly, and what the physical background behind the "story" is. I really liked physics and was good at it, but I chose Earth science to answer those questions using physics and mathematics.

After I entered the university, I found that the questions I had raised were solved by understanding the physical properties of minerals in the Earth. For example, the "slip" between rock layers, which generates earthquakes, can be understood by the knowledge of the friction of quartz, which is the most abundant mineral in the crust.

Moreover, mineral hardness can also be used to estimate Earth's internal structure. When an earthquake occurs, waves of shaking propagate through the Earth, and the hardness of minerals determines the velocities of waves. We can determine wave velocities by using many observation points on the sea and land. By analyzing wave velocities, we can determine changes in temperature or fluid content within the Earth, because mineral hardness depends on temperature and the presence of fluid.

However, understanding physical properties, such as the friction and hardness of minerals in the Earth, is difficult because we cannot directly observe them in the deep Earth. Scientists try to overcome these difficulties through laboratory rock experiments. However, those laboratory conditions and Earth conditions are, of course, different from each other. For example, the temperature in the mantle is above 1200 ℃, and the pressure is in the order of GPa. 1200 °C is about as hot as a flame, and 1 GPa is roughly 100 times greater than the water pressure at the bottom of the Mariana Trench (10,000 m depth). If there is no theory that connects the laboratory and the mantle, even if laboratory experiments have determined the physical properties of minerals with great precision, we cannot say anything about the Earth's interior.

Then, how to create such a magical theory that connects completely different scales? This is a problem I am expected to solve in my current research. To solve this big problem, experiments on "pseudo-rock", which mimics a real rock, are key to creating the theory. If we choose an appropriate pseudo-rock, the microscopic physics inside the rock and that inside the pseudo-rock have in common. For example, if we choose Borneol, one of the air fresheners, it can reproduce the physics of high-temperature rock near room temperature. In fact, the hardness of real rock under high temperature and that of pseudo-rock under room temperature follow the same law. We are developing a theory to explain why the two different materials exhibit the same temperature dependence.

If the theory can be established, we can conduct a pseudo-rock experiment at room temperature instead of a real-rock experiment at high temperature. The former experiments are, of course, easier than the latter ones, so that we can measure more precisely. Moreover, we can address areas that real rock experiments cannot. These precise, comprehensive basic data on pseudo-rock helped to understand not only the physics of pseudo-rock but also that of real rocks.

As explained above, the physics inside the Earth is so large-scale that we can only attack it at the laboratory scale and connect these two scales through theory. The key to constructing the scaling theory is the universality of the material, common to both the Earth's interior and the laboratory. By determining the scaling law, we can truly understand the dynamics within the Earth and partly answer the question I asked myself as a child. Although this may appear to be a long journey, we will seek to resolve these problems over the long term.

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