Does dark magma lurk in deep Earth?

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A composite image of the Western hemisphere of the Earth. Credit: NASA

(Phys.org) —A key to understanding Earth's evolution is to look deep into the lower mantle—a region some 400 to 1,800 miles (660 to 2,900 kilometers) below the surface, just above the core. Data have suggested that deep, hot, fluid magma oceans of melted silicates, a major Earth material, may reside above the core-mantle boundary. Researchers including Carnegie's Alex Goncharov have found, using high-pressure experiments with a proxy material, that the deep Earth materials conduct far less heat under increasing pressure than previously thought. The finding suggests that pressure is more important than current thinking and it is in direct contrast to what is found with the most abundant heat-conducting substance in the vicinity. The results indicate the presence of dense, dark magma heat traps that could affect the flow of heat across the core-mantle boundary revealing a different model of heat transport in this region.

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Since scientists can't sample the Earth's deep interior, they study how seismic waves travel through the Earth to determine whether material is solid, liquid, or has other features. The detection of anomalous low-wave velocities suggests that dense, gravitationally bound melted silicate exists at the core-mantle boundary. However, direct measurements of the ability of this material to carry heat have not been technically possible. The research team studied two forms of silicate glass, an analogous material, under pressures up to 840,000 times atmospheric pressure, mimicking conditions of the core-mantle boundary.

Heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity. To observe how materials conduct heat, scientists manipulate materials while monitoring their physical properties. For example, under certain conditions minerals transmit light. Researchers can measure changes in transmission through the material induced by increased pressure, which affects the electronic structure and consequently thermal transport properties.

The team, led by Motohiko Murakami of Tohoku University (Sendai, Japan), measured the visible and near-infrared optical absorption of two types of silicate glass subjected to enormous pressure generated between two diamond tips in an anvil cell. The method allowed the scientists to detect tiny changes in the energy levels of the iron-enriched silicate glasses as it underwent pressure increases. The findings were further supported using a technique called Mössbauer spectroscopy, which showed changes in electronic configuration of iron ions that correlated with the observed increase in optical absorption.

"We were totally surprised to find that the radiative thermal conductivity decreases with pressure for both glasses," remarked Goncharov. "This result is in contrast to what is observed with the other major constituent of the lower mantle, perovskite. The heat transfer rate for the glass is about 5-25 times less than that of silicate perovskite—such a difference would strongly affect the flow of heat at the core-mantle boundary. It suggests the formation of deep, dark magmas with higher heat absorption than the surrounding material. This means it could trap heat from the underlying core and could lead to large-scale thermal upwellings called superplumes."

He continued: "To gain a greater understanding of what is happening in this region, scientists need to come up with novel techniques for in situ measurements of thermal transport properties under simultaneous conditions of high pressure and high temperatures in fluid silicates. These experiments are currently extremely challenging, but they should become possible with the developments of new pulsed-laser techniques coupled to laser-heated diamond anvil cells, which are currently underway in our Carnegie lab. Our goal is to look at the real melted silicate at very high temperatures, which in principle could reveal different properties than the glasses we looked at."

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