Giant impacts stochastically change the internal pressures of terrestrial planets

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Pressure is a key parameter in the physics and chemistry of planet formation and evolution. Previous studies have erroneously assumed that the internal pressures in terrestrial planets monotonically increase with mass during accretion. We use smoothed particle hydrodynamics and potential field method calculations to demonstrate that changes in thermal state and angular momentum caused by giant impacts can lead to significant variations in the internal pressures of growing planets.

Using the Moon-forming giant impact as an example, we show that the internal pressures after the collision could have been less than half that in present-day Earth. Counterintuitively, in many cases, the pressure in the post-impact body is lower than in the largest of the colliding proto-planets. Lower pressures in the aftermath of giant planets may reconcile the apparent contradiction between the expected near whole mantle melting due to giant impacts and the mid-mantle average pressures of metal-silicate equilibration inferred from the abundances of moderately siderophile elements in the terrestrial mantle. The lower internal pressures after some Moon-formation scenarios will change how the mantle solidifies. For example, there would be no substantial basal magma ocean after a high-angular momentum Moon-forming impact. The sensitivity of a planet's evolution to its internal pressure opens pathways to use geochemical and geophysical observations of the present-day Earth to test different lunar origin scenarios.

The current pressure profile of Earth was not established until Earth cooled and the Moon receded, a process that may have taken up to tens Myr after the last giant impact. Pressure increases would have driven phase changes in the mantle, potentially including partial melting in the lowermost mantle. Pressure-induced phase transitions during the recovery of a body after a giant impact are a previously unrecognized phenomenon in planet formation.

Our work defines a new paradigm for pressure evolution during accretion of terrestrial planets: stochastic changes driven by impacts.