Mapping Global Lithospheric Mantle Pressure-Temperature Conditions by Machine Learning-Based Thermobarometry

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Understanding the temperature and pressure within Earth's lithospheric mantle is crucial for comprehending the dynamics of Earth's interior, its geochemical and geophysical properties, as well as their influence on magma formation and the stability of cratons. While traditional mineral-based thermobarometers have provided valuable insights in estimating temperature and pressure, their reliance on specific mineral pairs and reactions limits their global applicability. Furthermore, as a type of high-dimensional data, mineral compositions have complex relationships that are difficult to capture by conventional methods, and these conventional methods are prone to overfitting, which can produce inaccurate results in certain cases. Our work introduces a new method using XGBoost to develop machine learning-based thermometers and barometers. These models are trained on a comprehensive dataset from 985 high-temperature and high-pressure experiments. This approach is designed to fully leverage the potential of high-dimensional data, offering more precise and widely applicable estimations while also preventing overfitting inherent in traditional methods. Comparison between machine learning models and classic thermobarometer reveals that the machine learning models significantly improve the accuracy in predicting temperature and pressure. This improvement can be attributed to the capability of machine learning models in processing the high-dimensional data of mineral pairs. The global application of these machine learning models has enabled a re-evaluation of the mantle's thermal conditions across diverse cratons. Most notably, the depth estimations to the lithosphere-asthenosphere boundary using machine learning thermobarometry typically exceed seismic measurements by approximately 40 km. This discrepancy suggests the presence of melt-bearing zones at the lithosphere-asthenosphere boundary.