New parameter enhances insights into the evolution of mantle's redox states

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Researchers proposed a "potential oxygen fugacity" parameter to directly compare the fO_2 characteristics of melts formed at different depths. Credit: IOCAS

The oxygen fugacity (fO_2) of the mantle controls the speciation and mobility of volatiles within it, influencing the composition of volatiles released during mantle-derived magmatic activity, and thereby regulating the composition of the atmosphere.

Researchers from the Institute of Oceanology of the Chinese Academy of Sciences (IOCAS), together with their collaborators, have recently proposed a new parameter, "potential oxygen fugacity," to directly compare the fO_2 characteristics of melts formed at different depths.

Current research on the fO_2 of the mantle primarily focuses on studying the fO_2 of mantle-derived melts. However, due to the increasing stability of Fe^{3+} in garnet with pressure, mantle fO_2 decreases with depth if mantle composition remains unchanged. Therefore, the fO_2 differences in melts originating from different depths might reflect variations in the depth of magma origin, which is strongly dependent on the mantle temperature, rather than inherent differences in mantle fO_2 ($Fe^{3+}/\Sigma Fe$ ratio).

The parameter researchers proposed is analogous to the classical definition of potential temperature and represents the fO_2 of the mantle at 1 GPa with an assumption of no melting during decompression.

Using the potential oxygen fugacity parameter allows direct comparison of the redox states of mantle sources from different depths, thereby constraining the evolution of the mantle's redox state.

"Deciphering the evolution of the mantle's redox state since the Hadean is crucial for understanding important scientific questions such as deep carbon cycling, atmospheric composition evolution, and the origins of life," said Dr. Zhang Fangyi, first author of the study and also a researcher from IOCAS.

The study was published in *Nature Communications* on Aug. 10.

Using the potential oxygen fugacity parameter they had developed, the researchers collected data on normal ambient mantle-derived basalts and mantle plume-derived komatiites and picrites globally since 3.8 Ga to constrain the evolution of the mantle's redox state and thermal history.

The results showed that the fO_2 of Archean magmas was significantly lower than that of post-Archean magmas. Meanwhile, the fO_2 of magmas displayed a strong negative correlation with mantle potential temperature and melting pressure.

"This indicates that the high potential temperature of the Archean mantle, causing deep and extensive partial melting, might have resulted in the lower fO_2 of Archean magmas," said Dr. Zhang Fangyi.

After normalizing the fO_2 of all mantle-derived magmas to the potential oxygen fugacity, Zhang and his colleagues found that the fO_2 of both ambient mantle and mantle plume sources (lower mantle) has remained constant since the Hadean.

"The variations in the fO_2 of mantle-derived magmas were due to changes in melting depth and extent," said Associate Prof. Vincenzo Stagno, co-author of the study and a researcher from Sapienza University of Rome.

Changes in the fO_2 of mantle-derived magmas affected the composition of released volatiles and thus influenced the composition of the atmosphere. Previous studies suggested that the increase in mantle fO_2 since the Archean promoted a rise in atmospheric O_2 levels. However, this study reveals that the increase in fO_2 of mantle-derived magmas was in fact driven by a long-term cooling of the mantle, which resulted in decreased melting depth and thereby impacted atmospheric composition.

This study uniquely integrates the thermal state and redox state of the mantle as well as the evolution of the atmosphere's composition, thus providing "a new perspective for understanding the co-evolution history of Earth's multi-sphere system," said Prof. Sun Weidong, corresponding author of the study.

More information: Fangyi Zhang et al, The constant oxidation state of Earth's mantle since the Hadean, *Nature Communications* (2024). DOI: 10.1038/s41467-024-50778-z

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