Mineralogical Magazine (2026), **90**, 201–202
doi:10.1180/mgm.2026.10216

Editorial

Special Collection: Mantle Heterogeneity and Evolution

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This special collection in *Mineralogical Magazine* stems from the 5th European Mineralogical Conference in Dublin (2025) and is dedicated to the fascinating world of mantle petrology. The cratonic lithospheric mantle preserves a rich and complex record of Earth's deep processes, including partial melting, metasomatism, and fluid–rock interaction (Fig. 1). While most of the mantle consists of peridotitic, volatile-poor assemblages, small volumes of hydrous and carbonate-bearing lithologies reflect metasomatic modification, sometimes associated with subduction-related fluids. These metasomatic domains, though minor by volume, play a critical role in generating mantle-derived melts and in controlling the geochemical and mineralogical heterogeneity in the mantle. Understanding these processes becomes essential for reconstructing the thermal, chemical and volatile evolution of the deep part of our planet.

Innocenzi *et al.* (2026) explore how metasomatic veins in the lithospheric mantle contribute to the generation of unusual magmas. Using high-pressure experiments (2.7 and 5 GPa, 1200 to 1550°C) on phlogopite- and clinopyroxene-rich compositions, they show that partial melting can produce silica-poor, potassic to ultrapotassic melts comparable to natural kamafugites. These results highlight the importance of localized metasomatic domains as sources of chemically distinctive melts, demonstrating that small-scale heterogeneities can have a significant impact on the composition of magmas erupted at the surface. This study sets the stage for understanding how melt–rock interactions within metasomatized lithologies can create a spectrum of mantle residues and melt compositions.

The chemical diversity of cratonic peridotites also extends to their mineralogy, particularly orthopyroxene and olivine abundances. Silica enrichment, often expressed as elevated orthopyroxene content, and silica depletion, expressed as high olivine content, reflect variations in the intensity and nature of melt–rock interaction. Melai *et al.* (2026) investigate this complexity using high-pressure (5 GPa) high-temperature (1600 to 1690 °C) multi-anvil experiments simulating the reaction of Al-depleted komatiitic melts with fertile and depleted peridotites. Their results reveal a two-stage process: initial high-temperature olivine precipitation generates silica-depleted, olivine-rich residues, while subsequent reaction of the silica-enriched melt with residual olivine forms orthopyroxene-bearing, silica-enriched peridotites. These experiments demonstrate how reactive porous flow through depleted lithosphere can simultaneously produce chemically contrasting residues and diversify the composition of coexisting melts, providing a process-based explanation for the textural and compositional diversity observed in cratonic mantle xenoliths.

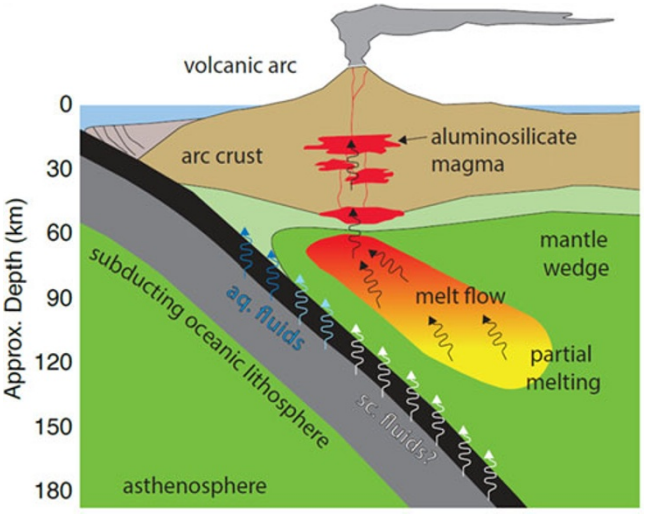


Figure 1. Schematic illustration of a subduction zone (from Ashley and Mookherjee, 2026 with permission) showing the descent of an oceanic plate into the mantle. Fluids released from the subducting slab rise into the overlying mantle wedge, inducing partial melting and metasomatic modification of the lithospheric mantle. These processes contribute to the formation of arc magmas, volcanic activity at the surface, and the chemical heterogeneity observed in subduction-modified mantle domains.

Similarly, Kaekane *et al.* (2026) focus on silica-rich harzburgite xenoliths from the Kaapvaal Craton (South Africa) to investigate the origins of orthopyroxene enrichment. By combining petrography, mineral chemistry, whole-rock geochemistry, and thermodynamic modelling, they show that high-pressure (4–5 GPa, 1600–1700°C) melt–rock interactions in the garnet stability field can produce orthopyroxene-enriched residues, probably involving silica-rich melts of komatiitic affinity. This work links metasomatic processes to broader mantle heterogeneity, reinforcing the idea that both local melt infiltration and high-pressure reactions contribute to the chemical evolution of refractory mantle lithologies.

Volatiles are another critical component of these processes, influencing melting, metasomatism, and mass transport. Ashley and Mookherjee (2026) investigate the mobility of H_2O-rich

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This paper is part of a collection on Mantle Heterogeneity and Evolution
Cite this article: Rinaldi M. and Melai C. (2026) Special Collection: Mantle Heterogeneity and Evolution. *Mineralogical Magazine* **90**, 201–202. https://doi.org/10.1180/mgm.2026.10216

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fluids under upper-mantle conditions using diamond-anvil cell experiments. By tracking the Brownian motion of quartz particles suspended in water at pressures below 2.5 GPa, they show that such fluids remain highly mobile, with very low viscosities, facilitating transport through the lithosphere and enhancing melt–rock interaction.

In addition, Befus *et al.* (2026) present a direct measurement of hydrogen isotopes in diamond-hosted olivine and orthopyroxene inclusions, revealing D-enrichment relative to a homogeneous upper mantle (average δD of –31 ± 59‰). This suggests that mantle hydrogen isotope compositions are spatially and temporally heterogeneous, and that local fluid processes associated with diamond formation can overprint broader mantle signatures. Together, these studies highlight the interplay between fluid mobility and melt–rock reaction in generating the chemical and isotopic complexity of the lithospheric mantle.

Collectively, these works emphasize the linked roles of partial melting, metasomatism, reactive melt–rock interaction, and mass transport in shaping the geochemical, mineralogical, and isotopic diversity of the cratonic lithospheric mantle. From the production of unusual ultrapotassic melts to the formation of silica-enriched and silica-depleted residues, and from volatile transport to hydrogen isotopic heterogeneity, they provide new insights into the dynamics, composition, and evolution of Earth's deep lithosphere.

This special issue has been made possible thanks to the dedication and contributions of the authors, as well as the time and effort provided by the Guest Editors: Caterina Melai and Michele Rinaldi. We also acknowledge the guidance and support of the principal editor, Roger Mitchell. Above all, we extend our heartfelt gratitude to the production and managing editor, Helen Kerbey and Kevin Murphy, whose oversight and coordination were essential to bringing this issue to completion.

Competing interests. The authors declare none.

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https://doi.org/10.1180/mgm.2026.10216 Published online by Cambridge University Press