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From deep H_2, to redox water and energy for life - *EMU Research Excellence Medal Lecture*

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Earth's long-term habitability is rooted in the dynamics of its deep interior. For billions of years, the exchange of materials between the surface and the deep Earth has sustained the biosphere by regulating the availability of life-essential elements such as carbon, hydrogen, and oxygen. The cycling of these elements among rocks, melts, and fluids defines the chemical architecture of our planet and shapes its geo-biodynamic evolution. Yet, the direct links between deep Earth processes and life remain largely unexplored.

A key control on geo-biological reactions is the redox state of volatile elements in geological fluids. In the shallow crust, abiotic reduced species such as H_2 and CH_4 are well documented and represent fundamental electron donors, providing energy sources for non-photosynthetic ecosystems—from early Earth environments to the present-day deep biosphere. In contrast, deeper volatile recycling has traditionally been viewed through the lens of oxidized species, mainly H_2O and CO_2, as inferred from volcanic emissions.

In recent decades, increasing attention has been devoted to the possibility that reduced chemical compounds may also form at greater depths within the lithosphere. In this contribution, I will summarize evidence indicating that such reduced fluids are not only generated in the lithosphere and transferred to the biosphere in quantities far greater than previously assumed, but also govern reaction pathways that may profoundly reshape our understanding of deep Earth processes and their role in planetary habitability. These processes include the existence of a hidden redox water cycle promoted by reactions between dry geological fluids and anhydrous mineral reactants that can alter the canonical models of deep water recycling.

Modulated by the formation and transformation of H_2, these mechanisms open a new perspective on the links between deep Earth dynamics and planetary habitability.