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Automated Mineralogy and Petrophysical Characterization of Serpentinized Rocks from the Pilar de Goiás Greenstone Belt: Implications for Natural Hydrogen Storage Potential

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Introduction

The global energy transition has increased interest in natural hydrogen (H_2) as a clean, in situ energy source. Among the most promising geological settings for H_2 accumulation are Archean greenstone belts, which frequently host serpentinized mafic and ultramafic rocks. The Pilar de Goiás Greenstone Belt, located within the Goiás Archean-Paleoproterozoic Terrane (central Brazil), comprises a thick sequence of komatiites, serpentinite-talc-chlorite schists, metapyroxenites, and amphibolites—rocks commonly associated with high-potential hydrogen generation systems. These lithologies, especially when pervasively serpentinized, enable H_2 production through water–rock interaction, primarily via the oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) in minerals such as magnetites and serpentine.

Methods and/or Theory

This research integrates field mapping, petrographic and geochemical and petrophysical characterization of ultramafic samples, and analysis of alteration-related mineral assemblages. Observed features such as spinifex textures, pillow lavas, and pervasive serpentinization suggest an extensive hydrothermal alteration history. Theoretical models show that H_2 generation is directly tied to Fe^{3+} formation in serpentine and magnetite, with the $Fe^{2+} \rightarrow Fe^{3+}$ redox transition releasing H_2. Notably, iron-rich olivine compositions yield significantly higher H_2 outputs—up to 2 to 10 times more than Mg-rich olivines—due to increased Fe partitioning in serpentine and magnetite. This is reinforced by studies from other serpentinized terrains such as West Iberia, where unexpectedly high H_2 fluxes were recorded during serpentinization of Fe-rich peridotites.

Results and Conclusions

Current geochemical data from volcanic rocks of the Pilar de Goiás Greenstone Belt confirm their high MgO content and the komatiitic affinity of the ultramafic units. These rocks have experienced at least two tectono-metamorphic events under amphibolite-facies conditions, followed by retrograde metamorphism in the greenschist facies. Such metamorphic overprints significantly altered the primary mineral paragenesis, leading predominantly to the formation of calcic amphiboles, chlorite, serpentine, talc, and magnetite. Electron microprobe analyses classified some preserved primary olivine crystals as fayalite—the iron-rich end-member of the forsterite–fayalite solid solution series. Petrographic observations reveal at least two distinct phases of serpentinization, potentially corresponding to separate episodes of hydrogen (H_2) generation. From a petrophysical standpoint, serpentinization is associated with a marked decrease in bulk density. Initially among the highest in fresh rocks, bulk density becomes one of the lowest once serpentinization is complete. Conversely, magnetic susceptibility increases significantly, particularly when correlated with the modal abundance of serpentine. These petrophysical changes not only indicate the extent of alteration but also provide important constraints for geophysical imaging of potential hydrogen-rich zones. Additionally, the ultramafic–mafic sequence is overlain by a thick sedimentary package, which may have facilitated the trapping and storage of the generated hydrogen. Together with preserved igneous and alteration textures, these characteristics point to favorable conditions for both the generation and preservation of H_2.

The regional geological context, analogues from known hydrogen-producing areas (e.g., Bourakebougou, Mali) support the classification of the Pilar de Goiás Greenstone Belt as a promising target for future geophysical exploration. This interpretation is consistent with current global research that identifies Archean and Paleoproterozoic greenstone belts as strategic sites for natural hydrogen resources.