A Potential Intraplate Serpentinization site of Sri Lanka as a Mars Analogue.

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Introduction Serpentinization has immediate planetary habitability importance given the hydrolytic alteration of primary ferromagnesian minerals like olivine and pyroxenes, producing H_2-rich fluids that facilitate carbon reduction and initiating an inorganic pathway for organic compound synthesis under varied environmental conditions [1,2]. Orbital mineral detections support evidence of past serpentinization in the martian crust, necessitating liquid-water-bearing horizons for sustaining the process [3, 4] Earth's serpentinites provide essential context in the absence of the retrieved martian samples, including for habitability investigations by future Mars missions [3,6]. We focus on Rupaha, possibly an intraplate serpentinized ultramafic intrusion in the Highland complex of Sri Lanka, aiming to present the characteristic geochemistry, mineral assemblages, and hydrothermal fluid signatures associated with present-day serpentinization, offering valuable insights and geochemical parameters relevant to martian serpentinization.

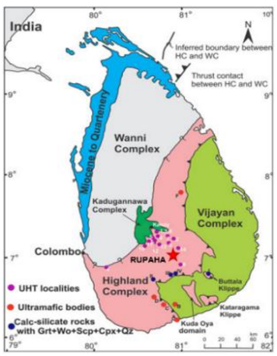

Figure 1*: Geological map of Sri Lanka (modified after [5]) showing the tectonic zones, the study area have been marked.*

Geological setting: The study area Rupaha is within the Highland Complex (HC) of Sri Lanka (Fig. 1). The Neoproterozoic Highlands record a geological history marked by accretionary setting, combined by double-sided subduction of Wanni and Vijayan arcs during the closure of the Mozambique Ocean [7]. Hence, the HC itself is analogous to the Cambrian Himalaya in Sri Lanka, formed through the collisional events associated with the final assembly of Gondwana [7]. Serpentinized ultramafic rock formations, occurring sporadically in the western part of Rupaha, extend over approximately 2 kilometers, displaying variable thickness from a few meters in the northern section to several hundred meters near the 'Garandu Kandura' river tributary [8,9]. Although the age of the ultramafic intrusion is unknown, its cross-cutting relationship with the granulite country rocks indicates it occurred after the regional metamorphic event which peaked at ~550 Ma [7].

Field observations and preliminary sample analysis: During our 2023 field expedition to the Rupaha outcrop at an elevation of 1040 meters, we observed massive serpentinites displaying a cross-cutting relationship with the country rock (Fig. 2a). The serpentinites exhibit varying degrees of serpentinization, evident in different shades from dark green to pale green (Fig. 2b, 2c). We did not observe any sharp contact between the protolith ultramafic rocks and the serpentinites. The serpentinite bodies are crosscut by pegmatitic veins (Fig. 2d), which contain K-feldspar and mica. Collected from various lithologies in the field, the serpentinite samples display a range of color from dark green to pale green indicative of different degrees of serpentinization. Initial analysis of major mineralogy and textures was conducted using an electron microprobe at the Physical Research Laboratory, Ahmedabad, India.

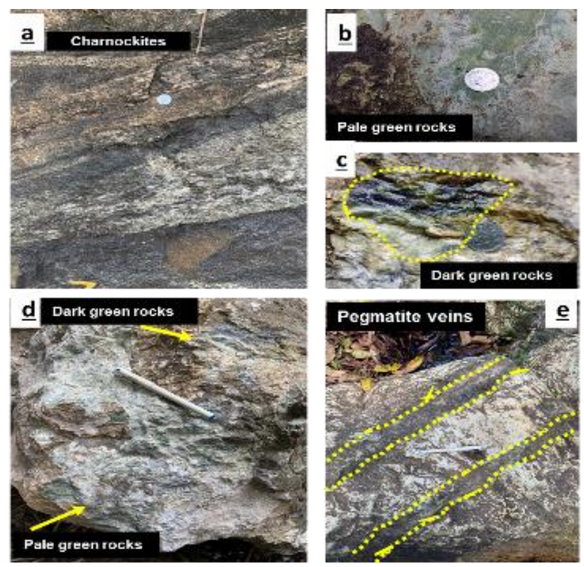

Figure 2*: Field photographs, (a) Charnockites, the country rock through which serpentinite is emplaced; (b) Pale green rocks; (c) Dark green rocks; (d) Massive serpentinites showing different degrees of serpentinization; (e) Pegmatite veins crosscutting the serpentinite* rocks.

Results: The dark green rocks, which preserve the protolith's olivine and pyroxene grains, show a typical mesh texture (Fig. 3a), indicating the occurrence of serpentinization along the olivine grain boundaries. The serpentine composition is Mg-rich (Mg# 95-99). Phlogopite is present in the dark green rocks. In contrast, the pale green rocks show no evidence of relict olivine, indicating a higher degree of serpentinization (Fig. 3b).

Carbonate veins cross-cut across the serpentinites in the pale green rocks, with the Mg# values (96-99) similar to those in the dark green rocks. The bulk rock chemistry analysis [9] showed that dark green rocks had approximately 3-4 wt% FeO, while pale green rocks had around 1 wt%. Despite this, other major element compositions were similar, suggesting serpentinization is primarily an isochemical reaction. Furthermore, carbonate veins in the area were found to be characterized by Mg-rich carbonates [9]

Discussion: The tectonic setting of Rupaha, especially if characterized by intra-continental serpentinization, provides a unique opportunity to mimic single-plate martian settings. Unlike many serpentine deposits on Earth [10,11] often associated with plate obduction settings, Rupaha's intraplate location where the magma would have intruded or the mantle emplaced as enclaves suggests a rare opportunity to draw correlations with Mars. The lack of known plate boundaries inhibits carrying the interior ultramafics to the surface of Mars, facilitating intraplate settings as an important analog Earth site than at plate boundaries.

The Ultramafic body of Rupaha exhibits varying degrees of serpentinization, featuring mineral assemblages such as olivine-magnesite and serpentinites, mirroring remote sensing findings of Mg-rich serpentinites and magnesite on Mars [3]. The coexistence of olivine-rich rocks undergoing serpentinization alongside the emergence of magnesium carbonates serves as a crucial proxy, offering an essential opportunity to deduce a set of geochemical parameters relevant to the olivine – serpentine - Mg carbonate assemblages found in the Nilli fossae region of Mars [3].

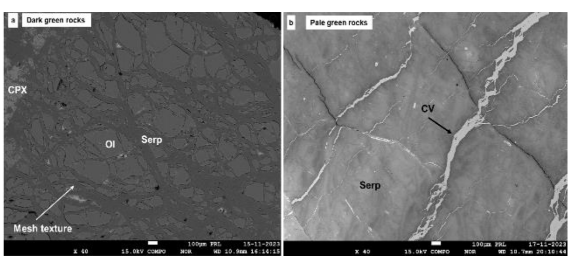

Figure 3*: The Back Scattered electron images of the Rupaha serpentinites, a) The dark green rocks; b) The pale green rocks.*

Future implications: Our comprehensive literature survey of terrestrial serpentinites, including a thorough examination of protolith compositions, reveals a remarkable consistency in their bulk chemistry [9,12,13,14,15]. The absence of discernible changes in bulk composition between protoliths and serpentinized rocks within the same geological bodies underscores the isochemical nature of serpentinization. The ternary diagram (FeO- MgO- CaO+ Na_2O +K_2O) (Fig. 1) illustrating the bulk compositions of terrestrial serpentinites along with available protolith data, has been constructed with the composition of the bulk silicate Earth (BSE). Remarkably, terrestrial serpentinites are found in both the Mg-rich and Fe-rich domains of the BSE composition. This intriguing observation leads us to postulate that more Fe-rich serpentinite protoliths could have originated from the melting of BSE, while Mg-rich serpentinites may be linked to mantle residue melting.

Applying this paradigm to Mars, where all the martian samples exhibit a more Fe-rich composition compared to the BSM, we anticipate the presence of Fe-rich serpentines in the martian settings. However, remote sensing data on Mars presents a counterpoint with Mg-ric serpentines and carbonates [16]. We hypothesize that these serpentinites may result from the alteration of a protolith formed by the residue of BSM melting, a composition not yet represented in martian sample data. This apparent discrepancy prompts further work into the complex serpentinization processes of the martian crust.

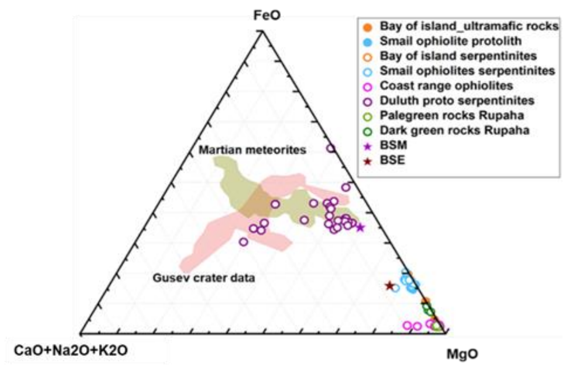

Figure 4: *Ternary diagram showing the bulk rock composition of serpentinites and some of the exposed protoliths. The shaded regions are representing martian samples*

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