Overview of Sri Lanka's rare occurrence of serpentinites within Proterozoic high-grade metamorphic basement rocks as a Mars-context research site

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Introduction:
Given roughly 300 – 600 °C alteration conditions in the presence of liquid water, serpentinization has wide-ranging significance to planetary habitability and mantle processes. Despite the many comparative planetology works on serpentinization, end member scenarios are not well characterized, and many have focused on ophiolitic settings [1]. This gap can be addressed by targeted studies of additional paleo-serpentinization zones, as in the island of Sri Lanka, especially for non-ophiolitic provenance [4] on stagnant lid planets like Mars. Serpentinization is identified on Mars at several locations by Mars Orbiters and landing Rovers, including Mg-serpentines and collocated magnesite, both of immediate relevance to Lankan counterparts [1].

Geologic overview:
Sri Lanka offers an excellent opportunity to investigate the Proterozoic-Precambrian Earth with high-grade metamorphic rock formed under a collisional suture in the middle of the Gondwana Supercontinent. The main three metamorphic units (Fig. 1) namely, Highland Complex (HC), Wanni Complex (WC) and Vijayan Complex (VC) compose amphibolite to granulite facies lithologies comprised of both sedimentary and igneous protoliths [2]. The HC (with >2 Ga old protolith materials) is a 550-600 Ma metamorphosed accretionary complex (e.g. [3]), suggested to have originated from the closure of the Mozambique Ocean in the Cambrian ([3]; [4]). The WC is thought to be a continental arc of >0.9 Ga age, while the VC may have originated as a volcanic arc system at ~1 Ga [5]. Specifically, the HC consists predominantly of metamorphosed supracrustal rocks such as sillimanite-garnet gneisses, quartzites, marble, and calc-silicates, along with some meta igneous units dominated by charnockitic gneisses, an ancient analogy to the Himalayan orogeny [3]. The Vijayan bears amphibolite-facies hornblende-biotite granitic gneisses predominantly. The Highland-Vijayan suture zone extends from the island's NE to the SE, with its central portion cutting through highland topography in a rugged terrain. We focused on the HC-VC suture zone that is dominated by accretionary sediments metamorphosed at least ~550 Ma ago [3]. Our emphasis on the HC-VC suture zone was aimed at several serpentinite bodies that are located along this zone (Fig. 1), particularly given their chemical distinctness from HC and VC (e.g., [4]).

Field Techniques:
In this study, we employed a GIS-grid strategy, leveraging multispectral satellite imagery and advanced computer vision techniques to precisely identify serpentine zones in Sri Lanka. The methodology involved overlaying a calibrated grid on satellite-derived terrain maps. Key parameters, such as grid orientation, interstitial spacing, and initial grid coordinates, were optimized to ensure efficient site selection for field sampling. This optimization was critical in targeting areas characterized by reduced vegetation cover, minimal human interference, and high probabilities of serpentine occurrence. The strategic application of this GIS-grid approach significantly enhanced the precision of our field sampling endeavors, providing a robust framework for exploring serpentinization processes and their Martian analogues.

Soils:
In the study area, serpentinite outcrops are limited to the above suture zone at its SE part which is a tectonic mixture of HC and VC lithologies. These serpentinite bodies and the top soils in this region contain elevated concentrations of Ni and Mn offering pedological insights from variably developed soils (e.g. [6], [7]), [8]).
Associated extensive Fe-oxide production in soils at the study area can relate Fe-rich Martian crustal explorations [8]. The occurrence of Mg-carbonate, serpentine, and talc is key evidence for their formation by subsurface serpentinization processes ([8], [9], [10], [11]).

When the crust is broadly Si-depleted and Fe-enriched compared to Earth [12], it increases the likelihood of widespread serpentinization if hydro-thermal conditions allow. The parent rocks that alter to produce Martian soil or its precursors are likely to be dominated by low-silicon and high-iron bulk abundance at the regional scale, resembling mafic and ultramafic geologic sites on Earth more than continental settings [13]. Serpentine soil may also affect the leaching of cations in the presence of perchlorates. An understanding of such processes would help to advance the currently limited knowledge of source-to-sink pathways for reactive halogens on Mars [14]. Hence, the presence of variably developed soils, some lateritic, and those with Ni and Mn-rich across this serpentinite zone offers a planetary end-case reference site for pedogenesis in serpentinites in the context of Mars-analog research.

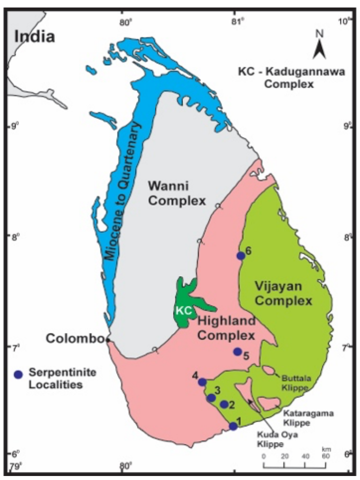

Fig. 1: A map showing lithotectonic subdivision of Sri Lankan Basement (modified after [2] and serpentinite localities. 1- Ussangoda; 2- Indikolapelessa; 3- Ginigalpelessa; 4- Katupotha; 5- Rupaha; 6- Yudhaganawa

Rocks:

Petrographical evidence of these serpentinites in the study area shows that they are predominantly antigorite-rich and typically carry remnants of precursor dunitic lithologies while associated with an episode of magnesite formation [4]. This is probably due to a highly potassic CO_2-rich melt influx. Such melt influx would metasomatize the mantle (Fig. 2) and the resulting magmas could crystallize zircons, which has given U-Pb age of ~ 485 ± 6 Ma [4]. Notably, Lanka's serpentinites are located in the dry climate zone, in which potential evaporation exceeds precipitation [15]. Characteristically, water springs located along this HC-VC suture and also proximal to this serpentinite zone indicate hydrothermal circulation of groundwater across hundreds of Ma time scales [17]. All-in-all, serpentinite studies anchored in the HC-VC tectonic suture of Sri Lanka provide an ideal situation to develop a sustainable planetary analog program on Martian serpentinization, tectonics, soil processes, habitability, and in situ resources for humans.

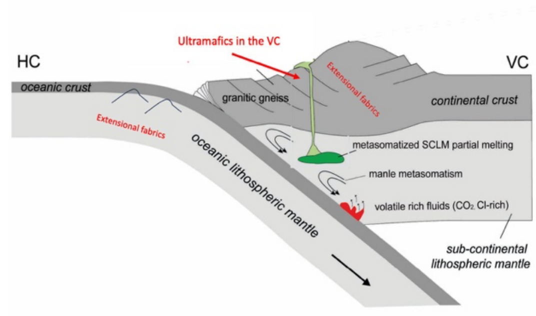

Fig. 2: Tectonic model for the origin of ultramafic intrusion where the magma is formed by partial melting of metasomatized volatile-rich mantle in a post-collisional extension environment (modified after [16])

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