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Geology of Sri Lanka: A Journey Through Ancient Landscapes and Unique Geological Features.

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ABSTRCT

Sri Lanka's geological landscape, predominantly composed of Precambrian strata, offers a critical window into the evolution of ancient continental fragments and the dynamics of supercontinent cycles. The island is divided into five major geological units: the Highland Complex, Vijayan Complex, Wanni Complex, Kadugannawa Complex, and Miocene sedimentary formations. Over 90% of Sri Lanka's surface is covered by Precambrian rocks, with the Highland Complex distinguished by granulite-facies rocks such as gneisses, quartzites, marbles, and charnockites, while the Vijayan Complex is characterized by amphibolite-facies gneisses and granites. These high-grade metamorphic terrains, dating back to the Archean and Proterozoic eons, provide key insights into the assembly and breakup of the Gondwana supercontinent, particularly during the Pan-African orogeny and Gondwana's fragmentation approximately 200 million years ago. Sri Lanka's geological stability, attributed to its central position within the Indian plate, contrasts with its dynamic tectonic history, including the northeastward movement of the Indian plate and the Himalayan uplift around 55 million years ago. The island also hosts significant mineral resources, such as globally important graphite deposits and gem-bearing sedimentary formations, alongside fossil records spanning the Jurassic, Miocene, and Pleistocene epochs. By integrating advancements in geochronology, petrology, structural geology, and paleontology, this study synthesizes field observations, geochemical analyses, and geophysical data to construct a comprehensive model of Sri Lanka's tectonic evolution. The findings enhance our understanding of Precambrian crustal processes, supercontinent cycles, and the formation of ancient continental nuclei, positioning Sri Lanka as a natural laboratory for studying Earth's deep-time geological history. This research underscores the island's significance in unraveling the complex interplay of tectonic, metamorphic, and magmatic processes that have shaped the planet over billions of years.

Article information | Key Words: Sri Lanka, Precambrian geology, Highland Complex, Granulite-facies metamorphism, Gondwana, Tectonic evolution, Paleontology.

Citation

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GEOLOGY OF SRI LANKA

ARAVINDA RAVIBHANU

Breathtaking view of Samanala Wewa Reservoir, as seen from Horton Plains National Park. Captured by Aravinda Ravibhanu © 2016.

INTRODCUTION

Sri Lanka's Precambrian basement has long been a cornerstone of geological inquiry, offering a window into the tectonic and geomorphological evolution of the Indian subcontinent and its role in the broader context of Gondwana's history. Since the early 20th century, the island's geology has been the subject of intense scrutiny, with seminal contributions from pioneering geologists such as Frank Dawson Adams, D.N. Wadia, Ananda Coomaraswamy, J.S. Coates, and L.J.D. Fernando. Their work has not only shaped our understanding of Sri Lanka's geological framework but also provided critical insights into the processes of uplift, erosion, and metamorphism that have sculpted its terrain over billions of years.

The geological history of Sri Lanka is deeply rooted in its Precambrian metamorphic basement, which forms part of the Gondwana supercontinent. This basement, characterized by high-grade granulites and polymetamorphic terranes, preserves a complex record of tectonic events, including crustal thickening, metamorphism, and exhumation. Early studies in the 20th century, primarily focused on morphological observations, laid the groundwork for subsequent petrological and structural analyses. These investigations revealed the intricate interplay between tectonic uplift and erosional processes, as well as the stratigraphic and metamorphic relationships between the island's major rock units.

The first systematic geological account of Sri Lanka (then Ceylon) was provided by Ananda Coomaraswamy in 1903 and 1904, who documented its mineral resources and laid the foundation for future research. This was followed by D.N. Wadia's (1929) pioneering work, which produced the first island-wide geological map. However, early studies predominantly emphasized geomorphology over mineralogy, reflecting the limited analytical tools available at the time. The advent of systematic rock classification by J.S. Coates (1935) marked a significant advancement, distinguishing between igneous and metamorphic suites and providing a clearer understanding of the island's lithological diversity.

Two contrasting theories emerged during this period to explain Sri Lanka's geomorphology: Frank Dawson Adams' Three Peneplains Theory (1929) and D.N. Wadia's Block Uplift Theory (1941). Adams proposed that the island's terrain was shaped by sequential erosional surfaces formed through gradual uplift, identifying three distinct peneplains—lowest, middle, and highest—each representing a different stage of geological evolution.

1. *Lowest Peneplain*: Coastal plains (<30 m elevation), rising to 90–120 m inland (e.g., Trincomalee to Hambantota).

2. *Middle Peneplain*: Steeply elevated to 760 m, marked by escarpments like Knuckles Massif and waterfalls (Diyaluma, Bambarakanda).

3. *Highest Peneplain:* Elevated to 1,500–2,450 m, comprising plateaus (Horton Plains) and peaks (Adam's Peak, Piduruthalagala).

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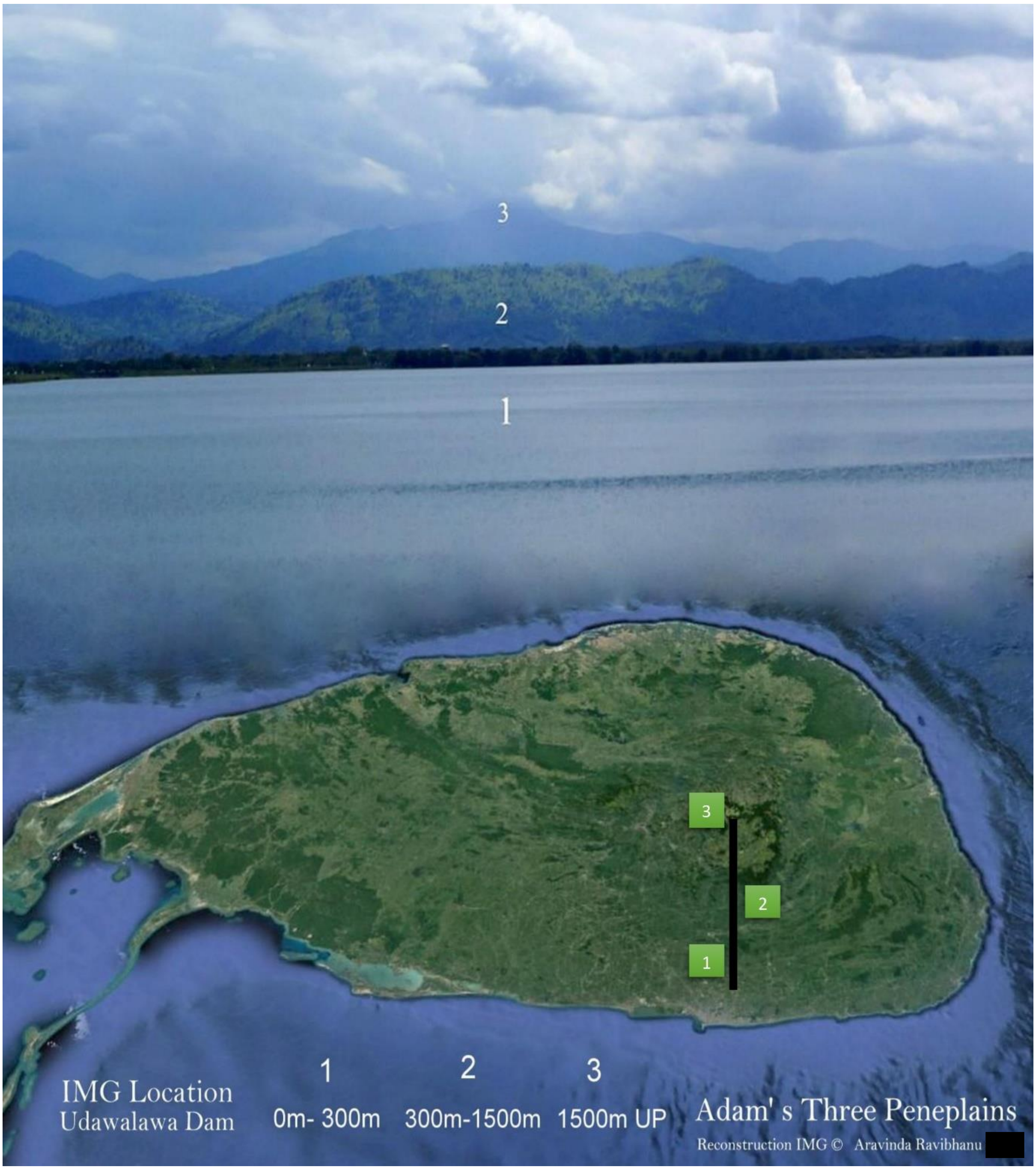

Figure 01: Highlights Adams' three distinct peneplains: 1. Lowest Peneplain, 2. Middle Peneplain, and 3. Highest Peneplain. A breathtaking glimpse into the layered history of the landscape. Captured by Aravinda Ravibhanu in 2016 and reconstructed in 2018.

In contrast, Wadia attributed the highlands to rapid vertical tectonic movements along faults, arguing that the highest peneplain was the youngest feature, formed by block uplift. These theories, though divergent, provided complementary perspectives on the island's uplift and erosion history, sparking decades of debate and further research.

Subsequent work by Coates (1935) and Fernando (1948) integrated petrological and structural analyses, refining earlier models and highlighting the complexity of Sri Lanka's basement. Fernando, in particular, challenged Wadia's simplified stratigraphic classification by

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demonstrating the heterogeneous nature of the Vijayan gneisses and their relationship to the overlying Khondalite Series. By the 1960s, advances in structural analysis and petrology had revolutionized the understanding of Sri Lanka's basement, revealing it to be a polymetamorphic terrane with a history of multiple tectonic and metamorphic events.

During the tenure of D.N. Wadiya as the Government Mineralogist of Ceylon, he authored a memorandum in 1941 proposing a groundbreaking theory on the formation of the island's highlands. Wadiya suggested that the highlands were formed relatively recently through the vertical uplift of a large crustal block along significant fault lines, a process he termed "Block Uplift." Contrary to the earlier hypothesis by Adams, Wadiya argued that the highest peneplain was the youngest, rather than the oldest. Wadiya identified a two-fold rock sequence in the region: the lower Vijayan Series, composed of igneous rocks, and the upper Khondalite Series, consisting of metamorphosed sedimentary rocks. He aligned with Coates' (1935) assertion that the younger Khondalite Series was associated with the Sri Lankan highlands, while the older Vijayan Series was predominantly located in the lowlands. This alignment supported Wadiya's Block Uplift theory, providing a framework to interpret the Khondalite Series as a younger geological group.

Furthermore, Wadiya classified Charnockites and zircon granites as integral components of the Vijayan gneiss. By the late 1940s, geologists had shifted their focus to the importance of identifying specific rock types rather than viewing the Sri Lankan basement as a homogeneous entity. In 1948, Fernando expanded on Wadiya's theory by proposing that the Vijayan gneisses served as the basement rocks for the Khondalite found in the central hills. Fernando also emphasized that the gneisses within the Sri Lankan basement were not uniform, advocating for their classification as a heterogeneous basement rather than a single cohesive unit. This period marked a significant evolution in the understanding of Sri Lanka's geological history, with Wadiya's Block Uplift theory and subsequent contributions by Fernando providing a foundation for interpreting the island's complex geological structure.

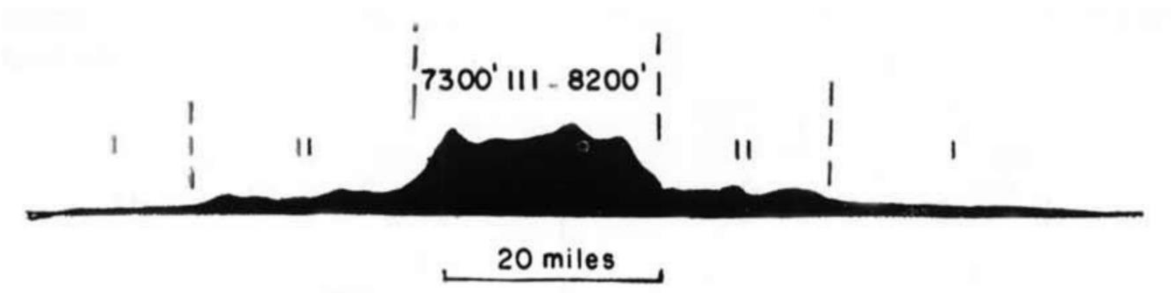

Figure 02: The formation of three distinct peneplains, as elucidated by D.N. Wadiya in his seminal 1942 study, represents a significant contribution to the understanding of geomorphological processes. Wadiya's research highlights the role of block uplift in shaping these extensive, nearly flat erosion surfaces, which are indicative of prolonged periods of tectonic stability followed by episodic uplift.

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The 1960s marked a pivotal era in the field of structural analysis, significantly advancing our understanding of Sri Lanka's geological evolution. During this period, Wadia's tectonic model was validated, while Adams' erosional chronology was reconciled, bridging two previously divergent paradigms: gradualist erosion and catastrophic tectonics. Modern geological studies now recognize the coexistence of both processes, including Proterozoic crustal reworking, exemplified by the intricate interplay between the Vijayan and Khondalite series, as well as Neogene uplift driven by block faulting.

Petrological investigations during this time revealed that Sri Lanka's basement constitutes a polymetamorphic terrane, characterized by high-grade granulites, as documented by Kröner et al. (2003). Fernando's seminal work further highlighted the complexity of the relationships between the Vijayan and Khondalite series, leading to significant revisions in stratigraphic nomenclature. Despite these advancements, certain discrepancies remain unresolved, such as the precise age of peneplains. These ambiguities underscore the need for advanced techniques like thermochronology to provide more precise temporal constraints and refine our understanding of Sri Lanka's geological history.

The integration of these findings reflects the dynamic interplay between erosion and tectonics, offering a more nuanced perspective on the island's geological evolution. Wadia's theories, once seen as conflicting with Adams' views, now serve as complementary frameworks within a broader, more cohesive geological narrative. This synthesis of ideas continues to shape contemporary research, driving further exploration and discovery in the field.

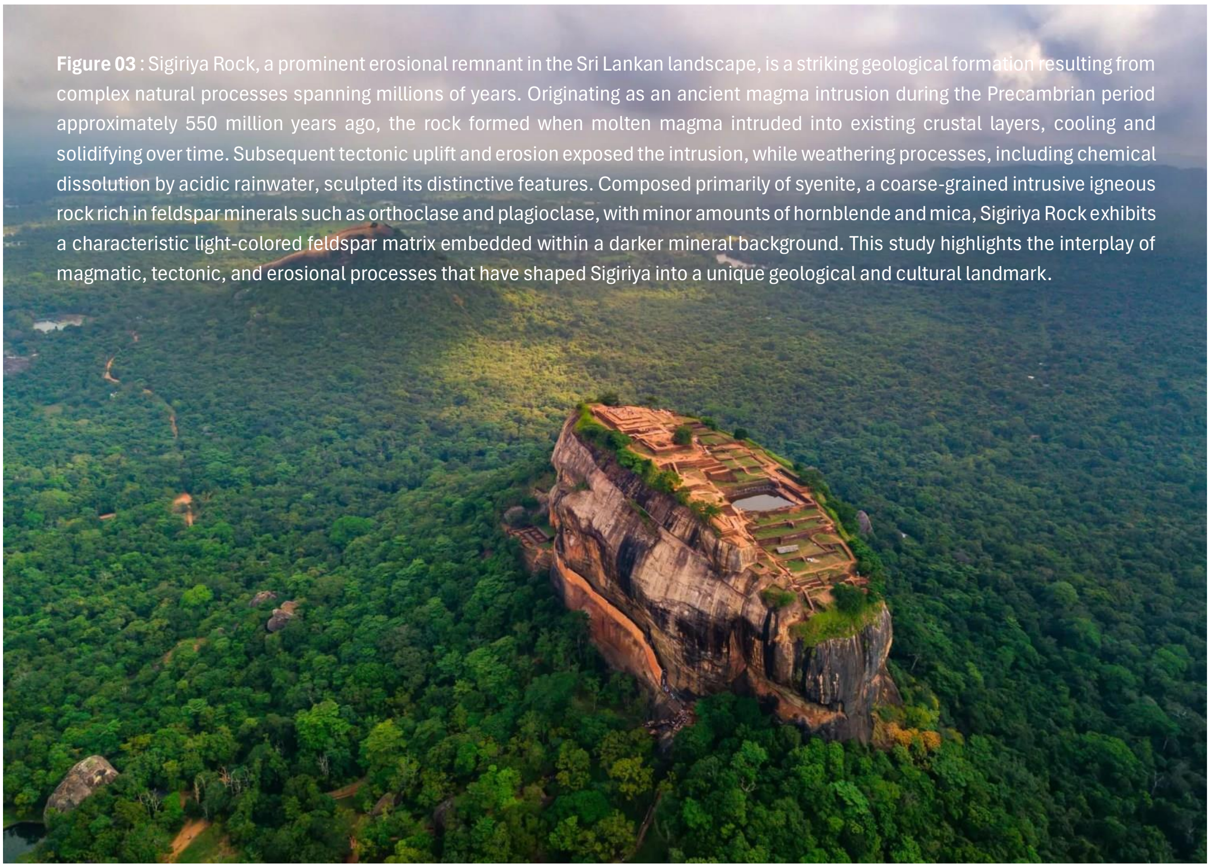

Figure 03 : Sigiriya Rock, a prominent erosional remnant in the Sri Lankan landscape, is a striking geological formation resulting from complex natural processes spanning millions of years. Originating as an ancient magma intrusion during the Precambrian period approximately 550 million years ago, the rock formed when molten magma intruded into existing crustal layers, cooling and solidifying over time. Subsequent tectonic uplift and erosion exposed the intrusion, while weathering processes, including chemical dissolution by acidic rainwater, sculpted its distinctive features. Composed primarily of syenite, a coarse-grained intrusive igneous rock rich in feldspar minerals such as orthoclase and plagioclase, with minor amounts of hornblende and mica, Sigiriya Rock exhibits a characteristic light-colored feldspar matrix embedded within a darker mineral background. This study highlights the interplay of magmatic, tectonic, and erosional processes that have shaped Sigiriya into a unique geological and cultural landmark.

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OVERVIEW OF SRI LANKAN GEOLOGY

Sri Lankan geology has garnered significant attention over the past two decades, with substantial contributions from international research groups. Pioneering work in the early and late 1980s by Japanese and German research teams, led by Prof. M. Yashida and Prof. A. Kröner respectively, has unveiled new geological units and provided a refined understanding of the island's geological framework. These findings, documented in a special issue of the *Journal of Precambrian Research*, have established a modern nomenclature for Sri Lanka's rock units, which is now widely accepted as the most up-to-date account of the region's geology.

Sri Lanka's geological history extends back to the Archean eon (4000–2500 million years ago, Mya). During the late Proterozoic to early Mesozoic, Sri Lanka occupied an internal position within the supercontinent Gondwana. However, the geological evolution of Sri Lanka during this period remains poorly constrained. Unlike adjacent regions such as India, East Africa, Madagascar, and East Antarctica, where the break-up of Gondwana resulted in intense brittle deformation, Sri Lanka exhibits only sparse evidence of tectonic and igneous activity during this time. The dispersal of Gondwana began during the Permo-Carboniferous, marked by the opening of intracontinental rift basins, with extension reaching its peak during the Jurassic–Cretaceous periods. The formation of oceanic crust during the separation of the Madagascar/India/Sri Lanka block from East Africa and East Antarctica is evidenced by seafloor anomalies in the Mozambique Basin (158 Ma) and south of Sri Lanka (134 Ma).

Following the initial opening of the proto-Indian Ocean, the India/Sri Lanka/Seychelles block separated from Madagascar and began its northward migration. This movement is recorded by late Cretaceous to middle Eocene episodes of seafloor spreading and late Cretaceous volcanism. At approximately 65 Ma, the India/Sri Lanka/Seychelles block finally fragmented, with India and Sri Lanka rifting away from the Seychelles along the Carlsberg Ridge. The collision of India with Eurasia around 50 Ma marked the end of the extensional phase, leading to a deceleration in seafloor spreading and positioning Sri Lanka in its current isolated geographic setting.

In eastern Sri Lanka, the first evidence of Mesozoic tectonic and igneous activity is dated to between 143 Ma and 170 Ma, based on K-Ar whole rock and Ar/Ar biotite ages obtained from doleritic dykes. Additionally, scattered occurrences of sedimentary rocks from the Jurassic, Miocene, and Quaternary periods are observed within the basement complex. Among these, Jurassic sedimentary rocks are confined to isolated faulted basins in the northwestern regions of Tabbowa, Andigama, and Pallama. The Tabbowa Formation primarily comprises well-bedded feldspathic sandstones, arkoses, siltstones, and mudstones, while the Andigama and Pallama beds are dominated by brown shales, black carbonaceous shales, and coal streaks.

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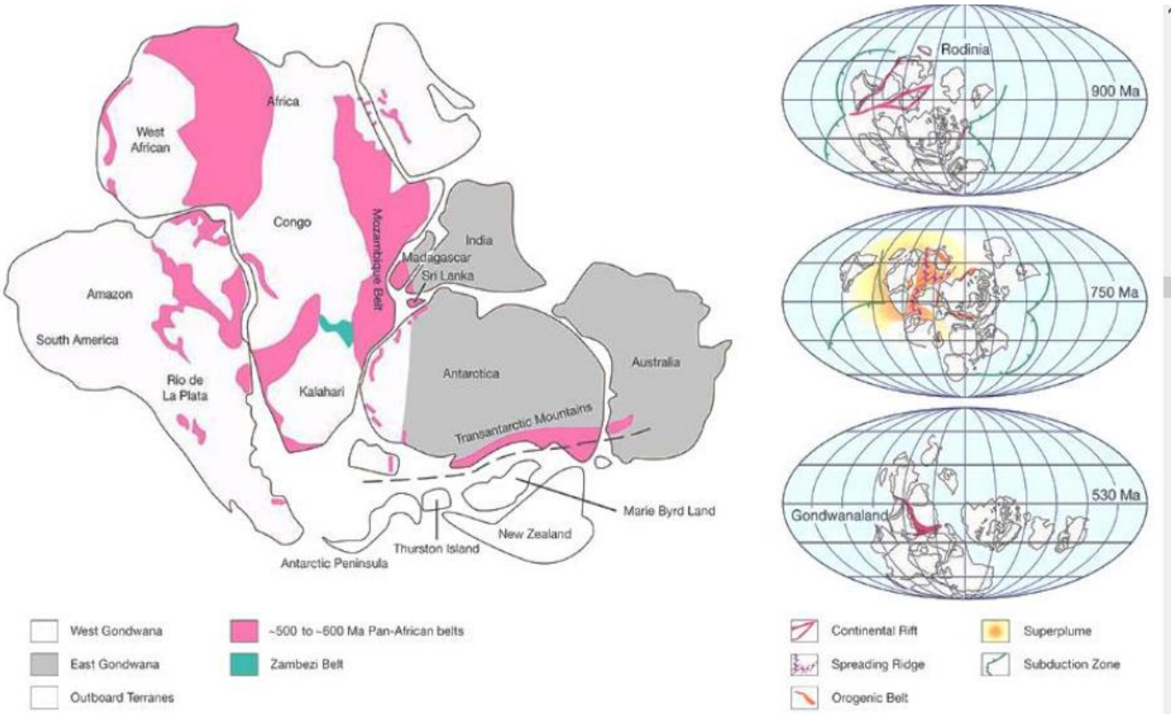

Figure 04: The Earth's geological history is marked by the formation and breakup of supercontinents, which have played a crucial role in shaping the planet's landmasses. One such supercontinent, Rodinia, was formed approximately 900 million years ago and began to fragment around 150 million years later. From the remnants of Rodinia, some of its fragments reassembled to form Gondwanaland, a landmass that would later become a significant component of the supercontinent Pangaea. Gondwanaland once connected present-day South America, Africa, Madagascar, India, Sri Lanka, Antarctica, and Australia, highlighting the dynamic nature of Earth's tectonic evolution. This geological history provides valuable insights into the distribution of continents and the processes that have shaped our planet over billions of years (Li et al., 2008; Dissanayake & Chandrajith, 1999).

Sri Lanka's Proterozoic Basement Complex Evolution

The basement complex of Sri Lanka represents a critical segment of the Earth's crust, offering profound insights into the tectonic evolution and metamorphic history of the Proterozoic era. Composed predominantly of high-grade metamorphic rocks, this complex is characterized by a diverse assemblage of ortho- and para-gneisses that formed under amphibolite to granulite facies conditions. These rocks provide a window into the dynamic processes that shaped the crust during the late Neoproterozoic to early Cambrian orogeny, a period marked by significant tectonic activity and metamorphic overprinting (Cooray, 1994). The basement complex is subdivided into three distinct tectonic provinces—the Highland, Wanni, and Vijayan complexes—along with the centrally located Kadugannava complex, each exhibiting unique lithological, structural, and metamorphic characteristics that reflect their complex geological histories.

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The Highland Complex, the largest and most prominent unit, forms the core of Sri Lanka's Precambrian basement. It is composed of Paleoproterozoic supracrustal assemblages and granitoid rocks that underwent granulite-grade metamorphism and charnockitization during the late Neoproterozoic to early Cambrian orogeny (540–550 Ma). This high-grade metamorphism is indicative of deep crustal processes associated with collisional tectonics and the assembly of Gondwana. The Wanni Complex, located northwest of the Highland Complex, comprises a suite of gneisses, granites, and amphibolite to granulite facies rocks, sharing a similar late Neoproterozoic–Cambrian tectonic history with the Highland Complex. In contrast, the Kadugannava Complex, situated in the central part of the island, is dominated by hornblende-bearing gneisses, while the Vijayan Complex in the east consists primarily of amphibolite facies gneisses and metasediments. The stark contrasts in rock types, metamorphic grades, and deformation timing between the Highland/Wanni and Vijayan complexes suggest that these units were juxtaposed during the final assembly of Gondwana, highlighting their significance in understanding the tectonic processes that shaped the supercontinent.

The lithological and structural diversity of these complexes, coupled with their distinct metamorphic histories, provides critical evidence for reconstructing the tectonic evolution of Sri Lanka within the broader context of Gondwana amalgamation. The Highland Complex, in particular, serves as a key unit for studying the processes of granulite formation and charnockitization, which are pivotal in understanding the thermal and tectonic regimes of deep crustal environments. The juxtaposition of these complexes during the late Neoproterozoic to early Cambrian orogeny underscores the role of Sri Lanka as a microcosm of the larger-scale tectonic processes that governed the assembly of Gondwana. This makes the basement complex of Sri Lanka an invaluable natural laboratory for studying high-grade metamorphism, crustal evolution, and supercontinent dynamics.

The Highland Complex (HC) of Sri Lanka represents a critical geological domain within the Gondwana supercontinent, characterized by a complex association of high-grade metamorphic rocks. This complex is predominantly composed of interlayered granulite-facies orthogneisses, derived from metamorphosed igneous protoliths, and para-gneisses, originating from clastic to calcareous shallow-water sedimentary precursors. The HC is distinguished by its intricate

 DOI: 10.63119/JEA05.2018

lithological assemblage, which includes meta-perlites, quartzites, marbles, metabasites, and charnockites, reflecting a dynamic tectonic and metamorphic history (Kröner et al., 2003; Kehelpannala, 1997).

A notable feature of the HC is the ubiquitous presence of mafic dykes, which have been structurally concordant with the host gneisses due to intense deformation and metamorphism. These dykes provide critical insights into the magmatic and tectonic processes that shaped the region during the Proterozoic (Santosh et al., 2014). Additionally, the HC hosts rare and mineralogically significant rock types, including calc-silicate gneisses, sapphirine-bearing granulites, cordierite-bearing gneisses, and corundum-bearing gneisses, which are exposed in minor quantities. These lithologies are indicative of ultrahigh-temperature (UHT) metamorphic conditions, suggesting peak metamorphic temperatures exceeding 900°C (Osanai et al., 2006).

In the southern part of the Vijayan Complex (VC), near Buttala and Katharagama, isolated exposures of granulites are interpreted as tectonic klippen, namely the Buttala klippe, Katharagama klippe, and Kuda Oya klippe. These klippen are considered allochthonous units thrust over the VC, representing remnants of the HC that were tectonically emplaced during the Pan-African orogeny (Kröner et al., 2003; Kriegsman, 1994). The presence of these klippen underscores the complex tectonic interplay between the HC and VC, providing valuable constraints on the collisional and exhumation processes that shaped the Sri Lankan basement.

The lithological and structural complexity of the HC, coupled with its UHT metamorphic signatures, makes it a key area for understanding the geodynamic evolution of Gondwana and the processes governing high-grade metamorphism in continental crust.

The geological evolution of Sri Lanka is characterized by the presence of several high-grade metamorphic terrains, among which the **Wanni Complex (WC), Vijayan Complex (VC),** and Kadugannawa Complex (KC) are prominent. These complexes provide critical insights into the Proterozoic tectonic and magmatic processes that shaped the island's crust. The Wanni Complex (WC) is an upper amphibolite to granulite-facies assemblage, comprising a diverse suite of rocks aged between 770 and 1100 Ma. This complex includes granitoid, gabbroic, charnockitic, and enderbitic gneisses, migmatites, and minor clastic metasediments, such as

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garnet-cordierite gneisses, as well as late to post-tectonic granites. A distinctive feature of the WC is the absence of thick marble and quartzite bands, which are otherwise dominant in the Highland Complex (HC) (Kröner et al., 2003; Kehelpannala, 1997).

In contrast, the Vijayan Complex (VC) is an upper amphibolite-facies suite of calc-alkaline granitoid gneisses, aged between 1000 and 1030 Ma. This complex is characterized by augen-gneisses, minor amphibolite layers derived from mafic dykes, and sedimentary xenoliths such as metaquartzite and calc-silicate rocks. The VC represents a distinct magmatic and metamorphic event, reflecting the calc-alkaline affinity of its protoliths (Milisenda et al., 1994; Kröner et al., 2003)

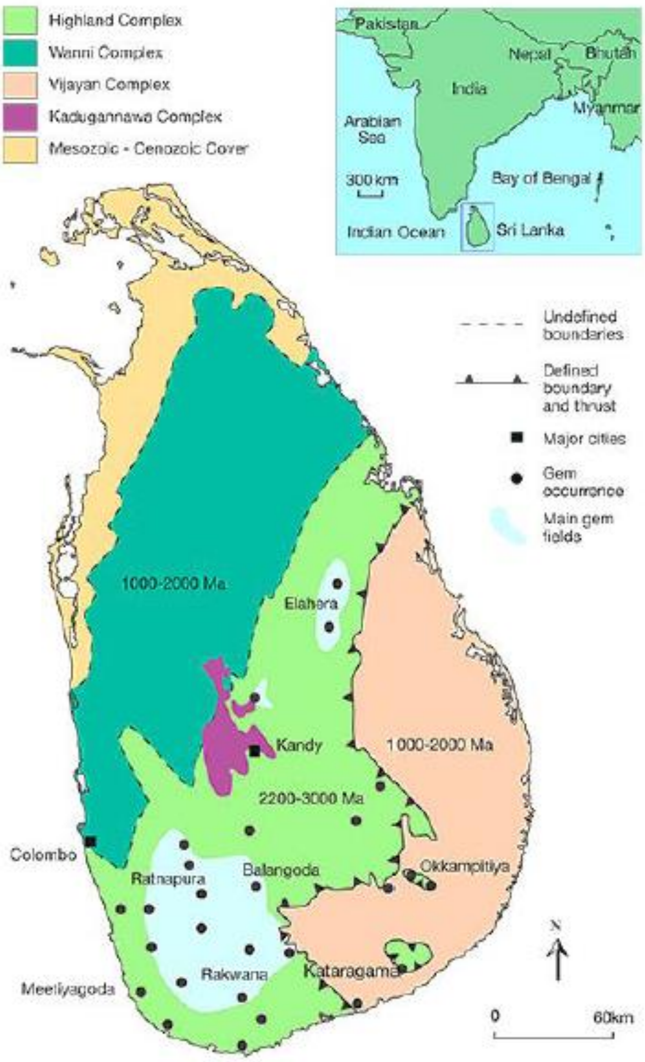

Figure 05 : Geological Map of Sri Lanka, Colombo: Geological Survey Department, Geological Survey and Mines Bureau, Sri Lanka. 1980.

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Igneous Rocks of Sri Lanka

The geology of Sri Lanka is predominantly characterized by high-grade metamorphic rocks, with igneous rocks being relatively rare. However, the occurrences of igneous rocks, particularly those of ultramafic origin, provide critical insights into the tectonic and magmatic history of the island. Among these, serpentinites, a group of ultramafic igneous rocks, are prominently exposed along the Highland Complex (HC) and Vijayan Complex (VC) boundary, particularly in regions such as Ussangoda and Ginigalpelessa. These serpentinites are believed to have formed during the Pan-African orogeny, a major tectonic event associated with the collision of East and West Gondwana. This event led to the over-thrusting of the HC over the VC, facilitating the intrusion of serpentinite-rich ultramafic magma into the crust, which subsequently crystallized into the distinctive green-colored serpentinite rocks observed today.

The tectonic boundary between the HC and VC extends from the southeastern coast of Sri Lanka, curving northeastward towards Trincomalee. Along this boundary, five major serpentinite outcrops have been identified, with Ussangoda hosting one of the largest exposures. Other significant occurrences include Ginigalpelessa and Indikolapelessa, both located near Udawalawa. These serpentinites are thought to have originated during or after the Pan-African event, with magmatic activity continuing from the Cambrian to the early Permian. The peak of this magmatic activity is believed to have occurred during the late Jurassic to early Cretaceous, leading to the formation of ultramafic rocks along the HC/VC boundary.

Figure 06 : Ussangoda : Serpentine soils, formed through the weathering of serpentine and ultramagnesian rocks rich in ferromagnesian minerals, exhibit unique geochemical properties due to their elevated heavy metal content. These metals, including nickel, chromium, and cobalt, significantly alter the soil's physical and chemical characteristics, creating extreme edaphic conditions that challenge plant survival and growth. In Sri Lanka, six distinct serpentine sites have been identified, with the Ussangoda site located along the southern coast in Hambantota standing out as a remarkable example of serpentine soil ecology. This site provides critical insights into the adaptation of flora to metalliferous environments and serves as a natural laboratory for studying biogeochemical processes in heavy metal-rich ecosystemsCaptured by Malaka Sanjaya Wijayanayaka.

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In addition to serpentinites, other igneous rocks of note include the carbonate-rich rocks derived from carbonatite magma, which form low hills at Eppawala. These deposits, known as the "Eppawala Apatite Deposit," are of significant economic importance due to their phosphate content. Furthermore, dolerite dikes of igneous origin are present on the eastern side of the island, with the Galllodai dike near Welikanda being the most well-known. Intrusive granites, although reported in areas such as Tonigala, Ambagaspitiya, and Arangala, have been found to exhibit varying degrees of metamorphism, complicating their classification as purely igneous rocks.

The Mineral Wealth of Sri Lanka

Sri Lanka, historically revered as "Ratna-Dweepa" or the Island of Gemstones, is globally renowned for its extraordinary wealth of high-quality gemstones. This reputation is deeply rooted in the island's unique geological endowment, particularly within the Highland Complex, a region characterized by its metamorphic rocks and granites. These geological formations have given rise to alluvial gravel deposits, which are the primary source of Sri Lanka's gemstones. These deposits, formed through the weathering of bedrock, accumulate in valley bottoms and host a diverse array of precious and semi-precious stones, making Sri Lanka one of the world's most significant gemstone-producing regions (Dissanayake & Rupasinghe, 1995; Zwaan, 1982).

The gemstones of Sri Lanka are not only diverse but also of exceptional quality. The island is particularly celebrated for its blue sapphires, which are among the most sought-after gemstones globally. Additionally, Sri Lanka is a prolific source of pink sapphires (often referred to as rubies), yellow sapphires, and other rare varieties such as alexandrite and cat's-eye chrysoberyl. The gemstone species found in Sri Lanka span a wide range, including corundum (ruby and sapphire), beryl (aquamarine and emerald), chrysoberyl (alexandrite and cymophane), zircon, spinel, quartz, garnet, topaz, tourmaline, and feldspar (Gunawardene & Rupasinghe, 1986; Zwaan, 1982). This mineralogical diversity underscores the island's geological complexity and its significance in the global gemstone market.

Beyond their ornamental use in jewelry, certain gemstones from Sri Lanka, such as sapphires, have specialized industrial applications. These include their use in infrared optical components

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and as durable windows in high-performance devices, highlighting the multifaceted value of these minerals (Katz, 1992). The gemstone industry is a cornerstone of Sri Lanka's economy, contributing significantly to foreign exchange earnings and providing employment to thousands across the island.

The cultural and historical significance of gemstones in Sri Lanka cannot be overstated. The ancient name "Ratna-Dweepa" itself reflects the deep connection between the island and its gemstones, which have been symbols of wealth, power, and spiritual significance for centuries (Dissanayake, 1991). However, the gemstone mining industry is not without its challenges. Socio-economic issues, such as inequitable wealth distribution, and environmental concerns, including land degradation and water pollution, necessitate the adoption of sustainable and responsible mining practices. Addressing these challenges is critical to ensuring the long-term viability of the industry and minimizing its ecological footprint (Dharmaratne & Wijesekara, 2004).

Gemstone Name	Mineral Group	Typical Colors	Uses	Economic Significance
Ruby	Corundum	Red (various shades)	Jewelry	Highly valuable, significant export
Sapphire	Corundum	Blue, yellow, pink, orange, green, purple, colorless	Jewelry, industrial applications (e.g., optics)	Major export, "Ceylon Sapphire" is world-renowned
Aquamarine	Beryl	Blue to greenish-blue	Jewelry	Relatively common, contributes to export market
Emerald	Beryl	Green	Jewelry	Highly valuable, found in Sri Lanka
Alexandrite	Chrysoberyl	Green in daylight, red in incandescent light	Jewelry	Rare and valuable, significant export

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Cat's Eye (Cymophane)	Chrysoberyl	Yellowish-green with a chatoyant band	Jewelry	Prized for its optical effect, contributes to exports
Zircon	Zircon	Various colors (blue, red, yellow, brown, colorless)	Jewelry, some industrial uses	Relatively common, part of the gem trade
Spinel	Spinel	Red, blue, pink, purple, black, colorless	Jewelry	Historically mistaken for ruby and sapphire, contributes to exports
Garnet	Garnet	Red, orange, yellow, green, purple, brown, black	Jewelry, abrasives	Various types found, contributes to the gem market
Topaz	Topaz	Colorless, blue, yellow, brown, pink	Jewelry	Relatively common, part of the gem trade
Tourmaline	Tourmaline	Various colors (pink, green, blue, black, multicolored)	Jewelry	Diverse varieties found, contributes to exports
Moonstone	Feldspar	White with a bluish sheen	Jewelry	Popular gemstone, particularly the "Ceylon Moonstone"
Quartz	Quartz	Colorless (rock crystal), purple (amethyst), yellow (citrine), pink (rose quartz), etc.	Jewelry, some industrial uses	Abundant, contributes to the gem and mineral market

Table 01 : Geochemical and Mineralogical Characterization of Gem Minerals in Sri Lanka: Implications for Economic Geology and Health Benefits : Aravinda Ravibhanu ©2017.

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Geochemical and Mineralogical Characterization of Sri Lankan Minerals: Implications for Economic Geology, Health Benefits, and Sustainable Resource Utilization.

Sri Lanka, an island nation in the Indian Ocean, is endowed with a remarkable wealth of industrial minerals that play a pivotal role in its economic development and industrial sectors. Among these, graphite stands out as a mineral of global significance due to its unique crystalline vein (lump) form, which is commercially available exclusively in Sri Lanka. This type of graphite is distinguished by its exceptional purity, ranging from 97% to 99.9%, making it highly sought after for advanced industrial applications. Vein graphite is utilized in the production of lubricants, carbon brushes, refractory bricks, and midget electrodes, and it is increasingly important in cutting-edge fields such as nanotechnology, lithium-ion batteries, and graphene technology. The economic value of graphite to Sri Lanka is substantial, as it is a major export commodity with growing opportunities for value addition, particularly through the production of graphene, a material with transformative potential in electronics, energy storage, and composite materials. (Jayawardena, 2013).

In addition to graphite, Sri Lanka is home to significant deposits of heavy minerals, including ilmenite, rutile, and zircon, which are concentrated in the beach sands of the Pulmoddai region. These minerals are critical raw materials for the production of titanium dioxide, a compound widely used in the manufacture of paints, plastics, and paper. Titanium metal, derived from ilmenite and rutile, is prized in the aerospace industry for its high strength-to-weight ratio and corrosion resistance. Zircon, on the other hand, is a key component in the ceramics and refractories industries. The formation of these mineral sands is a result of the weathering of ancient Precambrian crystalline rocks in the island's interior, with rivers transporting the weathered materials to the coast, where they are concentrated by wave, current, and wind action over geological timescales. These deposits represent a major export for Sri Lanka, with significant potential for further exploitation and value addition through advanced processing techniques (Dissanayake & Chandrajith, 1999; Herath, 1995).

Another industrially significant mineral found in Sri Lanka is apatite, or phosphate rock, with a major deposit located at Eppawala. This mineral is primarily used in the production of phosphate fertilizers, which are essential for the country's agricultural sector. The Eppawala deposit is estimated to contain approximately 60 million tons of apatite, with potential for the production of value-added products such as single superphosphate (SSP). The exploitation of this resource

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could significantly enhance Sri Lanka's self-sufficiency in fertilizer production and reduce dependency on imports (Dahanayake et al., 1986).

Sri Lanka also boasts high-purity silica sand deposits, with silica content exceeding 98%, which are utilized in the glass and ceramic industries. The exceptional purity of these deposits contributes to the high quality of Sri Lankan porcelain, which is recognized globally. Other industrial minerals found in Sri Lanka include various types of clay (kaolinite, ball clay, brick clay), quartz, feldspar, mica, calcite, dolomite, and garnet sand. These minerals have diverse applications in industries ranging from ceramics and construction to coatings and fillers, further contributing to the country's industrial and export sectors (Dissanayake & Rupasinghe, 1996).

Mineral Name	Chemical Composition (if applicable)	Major Uses	Economic Importance
Graphite	C	Lubricants, batteries, graphene production, refractory materials	Significant export, potential for value addition
Ilmenite	$FeTiO_3$	Production of titanium dioxide, titanium metal	Major export, raw material for various industries
Rutile	TiO_2	Production of titanium dioxide, titanium metal	Major export, high demand for its titanium content
Zircon	$ZrSiO_4$	Ceramics, refractories, foundry sands	Exported, used in local industries
Apatite (Phosphate Rock)	$Ca_5(PO_4)_3(F,Cl,OH)$	Production of phosphate fertilizers	Crucial for agriculture, potential for SSP production
Silica Sand	SiO_2	Glass manufacturing, ceramics	Supports local glass and ceramic industries
Clay (Kaolinite, Ball Clay, Brick Clay)	Various aluminum silicates	Ceramics, bricks, tiles, refractory materials	Used in local construction and

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			ceramic industries, some export
Quartz	SiO_2	Ceramics, glass, electronics	Used in local industries, some export
Feldspar	$KAlSi_3O_8$, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$	Ceramics, glass	Supports local ceramic and glass industries
Mica	Various silicate minerals	Electrical insulation, paints, fillers	Limited local use, some export
Calcite	$CaCO_3$	Cement production, agriculture	Used in local cement industry and agriculture
Dolomite	$CaMg(CO_3)_2$	Cement production, agriculture, refractories	Used in local industries
Garnet Sand	Various silicate minerals	Abrasives, water filtration	Some local use, potential for export

Table 02: Geochemical and Mineralogical Characterization of Sri Lankan Minerals: Implications for Economic Geology, Health Benefits, and Sustainable Resource Utilization. Aravinda Ravibhanu ©2017.

Sri Lanka, hosts significant occurrences of metallic ores, though these resources have not been as extensively exploited as its gemstones or certain industrial minerals. Among these metallic ores, magnetite, an iron oxide mineral, stands out due to its association with basic and ultrabasic rocks. A notable deposit prospect has been identified near Seruwila, where the copper-magnetite deposit is associated with cherty rocks, suggesting a formation environment influenced by the interaction of seawater with erupted lavas (Cooray, 1994; Dissanayake & Chandrajith, 1999). This geological setting is indicative of submarine volcanic activity, which is consistent with the island's complex tectonic history and its position within the Gondwana supercontinent.

In addition to the Seruwila deposit, a small-scale Kiruna-type magnetite-apatite deposit has been discovered within an ultramafic intrusion, further highlighting the diversity of Sri Lanka's metallic ore occurrences (Kröner et al., 2013). Kiruna-type deposits are typically associated with

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iron oxide-apatite formations and are of significant economic interest due to their high-grade iron content. Historical records also reveal the presence of a large magnetic iron ore deposit that was identified and proven in the early 1960s, underscoring the long-standing recognition of Sri Lanka's metallic ore potential (Jayawardena, 1976).

Copper occurrences, often associated with magnetite deposits, have been noted in the northeastern parts of the island, adding to the metallic resource base of the country (Dissanayake & Chandrajith, 1999). These copper deposits, though not extensively mined, represent a potential resource that could be explored and developed with modern technologies. The historical exploitation of iron ores in Sri Lanka dates back to the times of the early Sinhalese kings, indicating a long-standing, albeit modest, utilization of these metallic resources (Deraniyagala, 1992). This historical context suggests that with the application of advanced exploration techniques and mining technologies, there is potential for renewed interest and development in this sector.

The limited exploitation of metallic ores in Sri Lanka, compared to other mineral resources such as gemstones, presents both a challenge and an opportunity. Ongoing mineral exploration efforts have revealed the presence of various valuable deposits, indicating that the island's metallic ore resources could play a significant role in future economic development (Dissanayake & Chandrajith, 1999; Kröner et al., 2013). The potential for economic development through the exploitation of these resources is further supported by the island's geological diversity and the presence of high-grade deposits.

Paleontological Environment of Sri Lanka

Jurassic Period

Sri Lanka, an island nation with diverse ecosystems and bioregions, has long been a focal point for archaeological and paleontological research. The island's rich geological history is evidenced by the presence of artefacts, fossils, and subfossils of flora and fauna, which provide critical insights into its paleobiodiversity and evolutionary history. These fossils, categorized according to the geological time scale using relative dating methods, reveal a complex narrative of colonization, adaptation, and extinction of species over millions of years. The fossilization

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processes observed in Sri Lanka include petrifaction or permineralization, carbonization, infiltration or replacement, and compression, each contributing to the preservation of biological and geological records (Deraniyagala, 1955a; Cooray, 1984: Sumanarathna A.R 2017a).

The paleontological history of Sri Lanka can be divided into distinct periods: *the Jurassic*, *Miocene*, *Pleistocene*, and *Holocene epochs*. The Jurassic Period**,** dating back to 201–145 million years ago, is particularly significant due to its well-preserved fossiliferous plant imprints found in North-Western Sri Lanka. These fossils, embedded in sedimentary rocks such as sandstone, arkose, siltstones, and mudstones, suggest a semi-arid climate with brackish or freshwater sediments deposited in shallow deltas. The presence of conifers, cycads, and ferns, including species shared with the upper Gondwana formations of India, underscores the biogeographical connections between Sri Lanka and the ancient supercontinent of Gondwana (Deraniyagala, 1955a; Cooray, 1984). Notably, the Tabbova, Andigama, and Pallama regions in the North-Western Province have yielded significant Jurassic fossils, including leaves, stem fragments, and shoots, which provide valuable insights into the flora of this era.

Despite the Jurassic being renowned as the "Age of the Dinosaurs," the fossil evidence in Sri Lanka predominantly consists of plant remains, with limited macro-fossils such as *Elatocladus* plana* and *Cladophlebis* species recorded from Andigama (Sitholey, 1944). The Miocene, Pleistocene, and Holocene periods further contribute to Sri Lanka's paleontological record, with evidence scattered across the island, though research in the North-East remains limited, leaving gaps in our understanding of the region's geological and biological history.

This introduction highlights the importance of Sri Lanka's fossil record in reconstructing its paleoenvironmental and evolutionary history. By examining the geological and biological evidence from the Jurassic to the Holocene, researchers can better understand the island's role in the broader context of Gondwanan biogeography and its unique contributions to global paleontological knowledge.

The discovery of fossilized remains of marine organisms provides critical insights into the paleoenvironmental and geological history of a region. Among these, the fossilized specimens of *Kuphus arenarius*, commonly referred to as the 'Giant Teredo' (Family: Teredinidae), have garnered significant attention due to their implications for understanding the stratigraphic and temporal context of the Oligocene and Miocene epochs. The first documented discovery of

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Kuphus arenarius in Sri Lanka was made by Deraniyagala in 1969 at Arna Kallu. Deraniyagala (1969a, 1969b) speculated that the presence of *Kuphus sp*. in these deposits suggested the existence of an Oligocene geological layer in Sri Lanka, as this genus is typically associated with lower Miocene or upper Oligocene strata. This finding was pivotal in establishing a temporal framework for the region's geological history.

Further evidence supporting the presence of *Kuphus* in Sri Lanka emerged in 2008, when another fossilized Giant Teredo was discovered at the Aruwakkalu quarry site. This specimen was exposed on a rock face following a blast, highlighting the serendipitous nature of such discoveries. The recurrence of *Kuphus* fossils in Sri Lanka underscores the importance of these organisms as biostratigraphic markers and their utility in reconstructing the paleoenvironmental conditions of the region during the Oligocene-Miocene transition. These findings collectively contribute to a deeper understanding of the geological and paleontological history of Sri Lanka, offering a window into the ancient marine ecosystems that once thrived in the area (Sumanarathna, A.R 2017b).

Figure 07: Fossilized stem segments of Pteridophytes preserved in mudstone through the process of compaction. Recent observations indicate the preservation of 10-15 stem fragments, with a total approximate weight of 195.6 grams. Aravinda Ravibhanu ©2015.

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Miocene Period

The Miocene Period, spanning approximately 23 to 5 million years ago, was a time of significant geological and biological transformations globally. During this period, Sri Lanka was geographically separated from mainland India due to the submersion of the land bridge connecting the two regions. This separation occurred under a greenhouse-like climate, which characterized much of the Miocene (Goonetilleke, 2000). Key geological events during this era included the uplift of the Himalayan Mountain range and the fragmentation of parts of Asia, leading to the formation of large islands such as Sri Lanka, Sumatra, and Borneo. Concurrently, the Miocene witnessed the diversification and migration of mammals, including hyenas, giraffes, antelopes, and deer, across Asia and Europe. Marine ecosystems also flourished, with the emergence of Sireneans and the first appearance of Cetotheriid whales during the lower Miocene (Goonetilleke, 2000).

Figure 07: Recrystallized mold fossils of gastropods with preserved cast portions, discovered by Kaml Abeywardena in 2013 at the Aruwakkalu fossil site, Sri Lanka. Specimen highlights exceptional taphonomic preservation. Image credit: Aravinda Ravibhanu ©2015

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In Sri Lanka, the Miocene is represented by distinct geological formations, including limestone in the Jaffna Peninsula and sandstone in the southeastern region of Minihagalkanda (Cooray, 1984). These formations, now largely degraded, primarily contain fossils of corals and bivalves, indicative of intertidal environments. However, the Aruwakkalu area in the Puttalam region stands out as a site of exceptional paleontological significance. Here, a thick, ferrous-rich soil layer, known as the 'Red Bed,' overlies Miocene deposits and preserves a rich assemblage of fossils. These fossils include a diverse array of marine and terrestrial organisms, such as gastropods, bivalves, echinoderms, marine algae, tube worms, stingrays, whales, dolphins, fish, tortoises, and turtles, reflecting a high level of biodiversity during the Miocene (Deraniyagala, 1969b). The presence of both deep-sea and intertidal species, such as dugongs, whales, and freshwater gastropods, suggests that the Aruwakkalu area was once a dynamic environment with both marine and freshwater influences, including a river system (Deraniyagala, 1969b).

Further evidence of Miocene marine environments is found at Minihagalkanda, located in Block II of Yala National Park. This site contains fossils of the shell *Ostrea virletti*, along with sponges and corals, indicating the presence of a prehistoric beach. However, unlike Aruwakkalu, no vertebrate fossils have been discovered at Minihagalkanda, highlighting the unique preservation conditions at Aruwakkalu (Cooray, 1984). The fossil-rich deposits at Aruwakkalu have also attracted industrial interest due to their high calcium content, leading to mining activities for cement production.

Quaternary period

The Quaternary period, encompassing the Pleistocene (2.6–0.01 million years ago) and Holocene (0.01 million years ago to present) epochs, represents a critical phase in Earth's history marked by significant climatic, ecological, and evolutionary changes. During the Pleistocene, key events such as the evolution and dispersal of modern humans (*Homo sapiens*) from Africa, the extinction of megafauna due to hunting, the development of stone tool technology, and the domestication of flora and fauna laid the foundation for human civilization (Deraniyagala, 2004). These epochs also witnessed substantial faunal overlaps, with many species adapting to or succumbing to the dynamic environmental conditions of the time.

DOI: 10.63119/JEA05.2018

In Sri Lanka, the Pleistocene and Holocene fossil record is predominantly preserved in the alluvial deposits of the Ratnapura District. These alluvial sediments, found in lagoons, riverbanks, and coastal areas, have yielded a wealth of fossil remains, often uncovered during gem mining activities. The fossil assemblages of Sri Lanka exhibit strong biogeographic connections with those of the Narmada and Shivalik regions in India, as well as with Java, Sumatra, Borneo, and Burma, reflecting the shared evolutionary history of these regions when they were part of a larger landmass (Deraniyagala, 2004). The so-called "Ratnapura Fauna" includes a diverse array of extinct species, such as three species of elephant (*Elephas* spp.), two rhinoceros' species (*Rhinoceros kagavena* and Rhinoceros *sinhaleyus*), and other megafauna like the hippopotamus (*Hexaprotodon sinhaleyus*), lion (*Leo sinhaleyus*), and tiger (*Panthera tigris*), among others (Deraniyagala, 2004). Thermoluminescence dating of rhinoceros teeth from Lunugala has provided an age estimate of 80,000 ± 20,000 years BP, further anchoring the chronology of these faunal remains (Deraniyagala, 2004: Sumanarathna A.R, 2016 & 2017b).

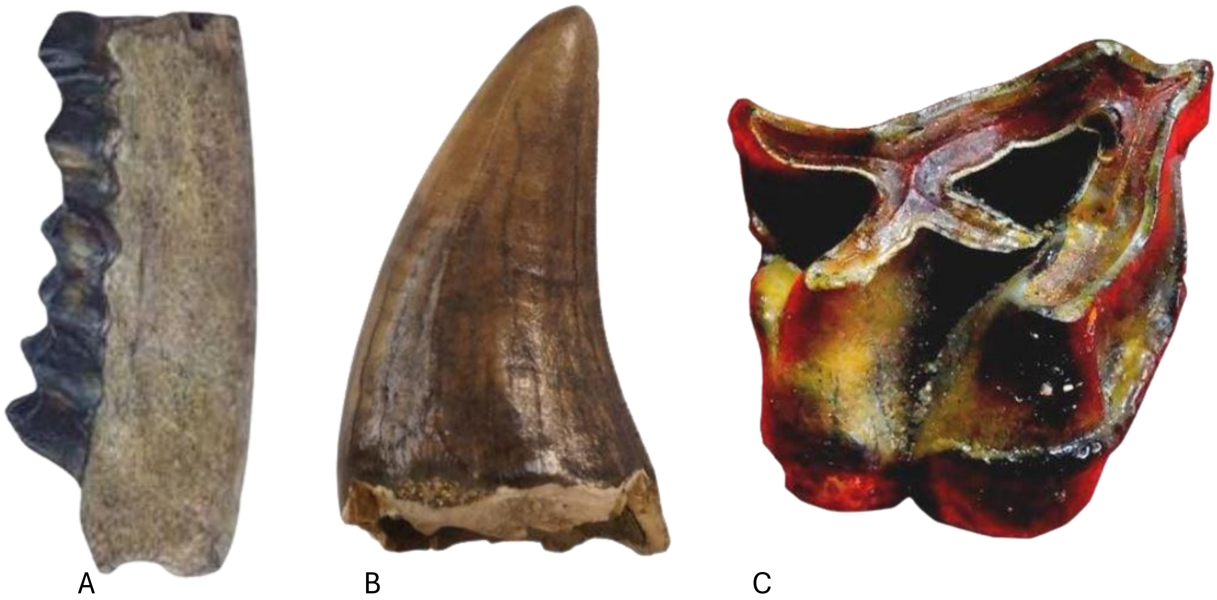

Figure 08 : (A) Fossil specimen Rusa unicolor (Catalog No. PSLSA01) – right mandible, displaying the outer (buccal) aspect with two premolars and molars. The fossil was excavated from Edandawela (Gem Pit), Kuruwita, Sri Lanka, as documented by Kamal & Aravinda Ravibhanu ©2007. (**B)** A fossilized canine tooth found in the right lower mandible of an individual from the Panthera tigris or Panthera leo sinhaleyus (Fossil No. PSLSA02), located in Galukagama MahaEla, Puwakattaovita (Gem Pit), Kuruwita, Sri Lanka, as documented by Kamal & Aravinda Ravibhanu in 2008. **(C)** First upper molar tooth of Rhinoceros spp. (Fossil No. PSLSA06) recovered from the Galukagama, Maha Ela (Gem Pit) site, Kuruwita, Sri Lanka. The specimen was documented by Kamal & Aravinda Ravbhanu (1994). (Sumanarathna et al., 2017a, 2017b, 2017c).

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A B

Figure 09: (A) Molar of Elephas maximus sinhaleyus (Fossil No. PSLSA07) discovered at Mawee Kubura (Gem Pit), Kuruwita, Sri Lanka. Source: Kamal & Aravinda, 1993. **(B)**: Rhinoceros sinhaleyus (Fossil No PSLSA03), specifically a proximal portion of the scapula, found in Kuruwita, Sri Lanka. This fossil was identified and documented by Kamal & Aravinda in 2007. (Sumanarathna et al., 2017a, 2017b, 2017c).

Pleistocene flora in Sri Lanka has been reconstructed primarily through pollen analysis and the identification of plant remains from gem pits. Studies by Puri (1941) and Vishnu-Mittre and Robert (1965) have revealed a rich arboreal vegetation dominated by Myrtaceae, with undergrowth including Strobilanthes, Moraceae, Sapindaceae, and Rutaceae, alongside ground vegetation such as Graminae and Cyperaceae. Fossilized wood remains from the Upper Pleistocene, including *Mesua* sp. (47,000 BP) and *Lagerstroemia speciosa* (7,520 ± 150 BP), further corroborate the presence of diverse plant communities during this period (Chowdhury, 1965). However, the preservation of Pleistocene flora in alluvial deposits is limited due to rapid

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decomposition, and cave deposits have yielded only a few hard-seeded species such as *Canarium* sp. and *Artocarpus* sp. (Deraniyagala, 2004).

The Pleistocene climate of Sri Lanka, as described by Deraniyagala (1958a), was characterized by three distinct phases: the Ratnapura Phase, Palagaha Turai Phase, and Colombo Phase. The Ratnapura Phase was marked by wet and cool conditions, supporting large lakes, swamps, and a savannah-rainforest mosaic inhabited by diverse fauna, including aquatic species like the hippopotamus (*Hexaprotodon sinhaleyus*) and crocodile (*Crocodylus sinhaleyus*). The subsequent Palagaha Turai Phase saw a shift to arid conditions, with the deposition of red earth and wind-blown sands, leading to the drying of lakes and swamps. The Colombo Phase, corresponding to the Early Holocene, heralded a return to wetter conditions, stabilizing into the climatic patterns observed today (Senanayake, 1994). Pollen studies by Premathilake and Risberg (2003) in Horton Plains further support these climatic fluctuations, identifying arid conditions in the Late Pleistocene and alternating wet and dry phases during the Holocene.

The faunal transition from the Late Pleistocene to the Holocene in Sri Lanka reveals both continuity and extinction. While some species, such as the gaur *(Bos sinhaleyus*), persisted into the Holocene before eventually disappearing, others adapted to the changing environment. The Holocene fauna, as documented by historical records such as those of Robert Knox (1681), reflects a dynamic interplay between climatic shifts and ecological resilience.

CONCLUSION

The geology of Sri Lanka offers a captivating narrative that spans billions of years, reflecting the dynamic processes that have shaped our planet. This island nation, nestled in the Indian Ocean, is characterized by a remarkable diversity of rock types, unique geological formations, and an abundance of mineral resources. Its geological history is deeply rooted in the Precambrian era, dating back to the earliest chapters of Earth's formation, and its integral role in the ancient supercontinent Gondwanaland underscores its global geological significance. Sri Lanka's geological heritage is not only a testament to the island's natural history but also a treasure trove for paleontological and mineralogical studies.

DOI: 10.63119/JEA05.2018

The geological journey of Sri Lanka has resulted in the formation of distinctive features that define its landscape. The mountainous Highland Complex, a prominent geological unit, dominates the central region of the island. This complex is composed of high-grade metamorphic rocks, including granulites, which provide valuable insights into the tectonic processes that occurred during the Precambrian era. The Highland Complex is juxtaposed with other geological units, such as the Vijayan Complex and the Wanni Complex, each contributing to the island's geological diversity. Sri Lanka's coastal landscapes, shaped by both ancient and ongoing geological processes, further enhance its geological richness. The island's iconic rock formations, such as Sigiriya and Danigala Rock, are not only geological marvels but also cultural and historical landmarks. Sigiriya, a massive granite outcrop, stands as a testament to the island's volcanic and erosional history, while Danigala Rock, often referred to as the "UFO Rock" due to its unique shape, offers a glimpse into the island's complex geological past.

The mineral wealth of Sri Lanka is another defining aspect of its geology. The island is world-renowned for its gemstones, including sapphires, rubies, and topaz, which have been mined for centuries and hold immense cultural and economic value. In addition to gemstones, Sri Lanka is rich in industrial minerals such as graphite, ilmenite, and apatite. Graphite, in particular, has played a significant role in the island's economy, with Sri Lanka being one of the world's leading producers of high-quality graphite. These mineral resources have not only contributed to the nation's economic development but have also shaped its cultural identity. However, the exploitation of these resources comes with significant responsibilities. While mining and resource extraction provide substantial economic benefits, they also pose environmental challenges. Sustainable and responsible practices are essential to ensure the long-term preservation of Sri Lanka's natural environment and the well-being of local communities. Balancing economic development with environmental conservation is a critical task for the nation as it moves forward.

The geological processes that have shaped Sri Lanka continue to influence its landscape today. Erosion, weathering, and tectonic activity subtly but persistently alter the island's topography, making it a living testament to the dynamic forces that have molded our planet over eons. The study of Sri Lanka's geology not only provides insights into the island's past but also offers valuable lessons for understanding global geological processes. The geology of Sri Lanka is a fascinating and multifaceted subject that reflects the island's deep connection to Earth's history.

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From its Precambrian origins and its role in Gondwanaland to its diverse landscapes and mineral wealth, Sri Lanka stands as a unique geological entity. As the island continues to evolve, its geological heritage serves as a reminder of the intricate and ever-changing nature of our planet.

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