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Editorial

New Horizons in Earth Systems, Resources, and Sustainability

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Earth is a dynamic system of various internal and external spheres that drive this dynamic planet as the unique example of living planet in the Solar System. Following its birth at about 4.53 billion years ago covered by a thick magma ocean, the planet developed its various internal spheres of the inner and out core, lower mantle and the lithosphere coupled with upper mantle and crust (Figure 1a). The Hadean anorthositic crust was eventually broken up by bombardments, destroyed and dragged down into the deep mantle [1]. The birth of water and initiation of plate tectonics marked a major turning point in Earth history. From the early plume-dominated regime and the stagnant lid tectonics [2], the planet transitioned into the plate tectonic world characterized by horizontal movement of lithospheric plates with rifting-subduction-collision tectonics by Paleo-Mesoarchean [3]. Magma factories at the Mid Ocean Ridge and at the convergent margins generated new crust and arc collisions built primitive continents which further grew through arc-continent and continent-continent collision, finally building large supercontinents [4]. The Early Earth was characterized by hot and shallow subduction of oceanic lithospheric, and with progressive decrease in mantle potential temperatures, the modern-style plate tectonic regime was established with cold and deep subduction. This marked another milestone with ocean water leaking into the mantle, lowering sea level, emergence of coastlines and birth of large rivers that provided nutrients through detritus for sustaining life. With the toxic oceans cleaned up by plate tectonics and emergence of oxygenated atmosphere, as well as the emergence of the protective umbrella of the ozone layer, land became habitable. Thus, plate and plate tectonics serve as the fundamental drivers of Earth's dynamic engines. Plumes act as giant pipes transferring materials from the core-mantle boundary to lower mantle, crust and into the atmosphere (Figure 1b).

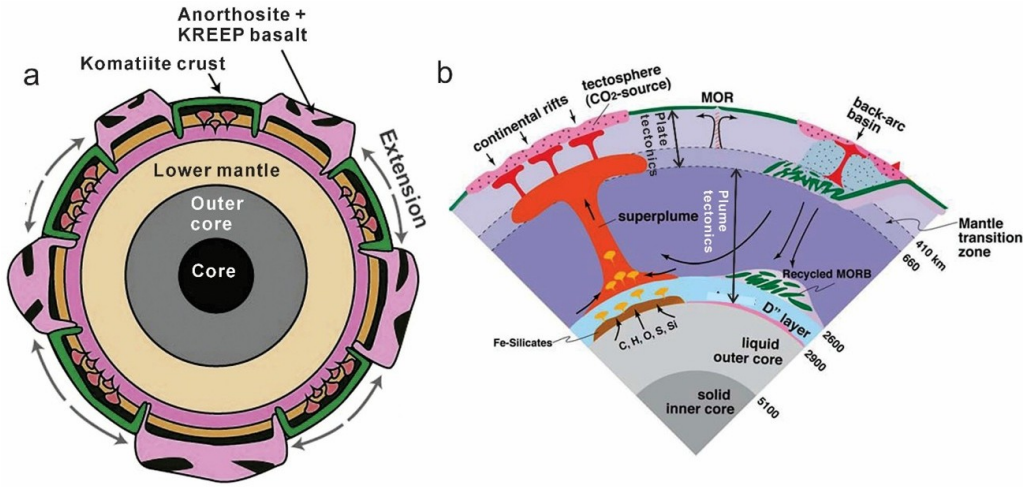

Figure 1. (**a**) Conceptual cross section of the Hadean Earth after the Magma Ocean stage showing the anorthositic continental crust with KREEP basalt, and komatiitic crust with plume-dominated tectonic regime (modified after [5]). (**b**) Schematic diagram illustrating the plate and plume tectonics. The recycled mid-ocean-ridge basalt (MORB) starts from the trench through mantle transition zone and finally down to the core-mantle boundary (CMB). It is then heated up by the outer core, leading to partial melting. The dense iron-rich melts accumulate on the bottom of the D"layer. The vertically rising superplume enters into the upper mantle, transforms to horizontal, and branches out into several hot spots. Plumes act as major pipes transferring material to and into the outer atmosphere (modified after [6]).

The secular evolution of Earth also witnessed the formation of several important mineral systems that serve as critical resources for the daily needs of the human civilization. Diverse mineral deposits were generated in different tectonic settings with the supercontinent cycle playing an important role in controlling the heterogeneous distribution of the major metallogenic belts on the globe. The conjunction of geodynamics, fertility of underlying crust and sub-continental mantle and crustal architecture, as well preservation are the key factors that dictate the present-day distribution of various mineral systems on Earth [7, 8].

The major external spheres of the Earth are hydrosphere, atmosphere and biosphere, all interlinked with geosphere as well as impacted by the anthroposphere of activities of living beings. The evolution of hydrosphere, atmosphere and biosphere took several hundred million years from an anoxic primitive planet to a life-sustaining dynamic system. The light elements like hydrogen and helium that covered the primate earth were replaced by one with carbon dioxide, methane, nitrogen and other gases with no free oxygen. One of the major turning points was the Great Oxidation Event [GOE] in the Archean-Paleoproterozoic stage following the emergence of photosynthetic organisms [9]. The birth of oceans marked the initiation of the hydrosphere, and through several millions of years or evolution, the toxic and anoxic early oceans were converted into the clean and blue oceans and life sustaining environment. With regard to the evolution of biosphere, there is little trace of evidence for life in the Early Earth. The primitive life originated as unicellular prokaryotes and subsequent appearance of eukaryotes followed by more complex and multicellular life forms and ultimately to the birth of human civilization. Chemotrophic ecosystems dominated the early stages of the biosphere which later became extinct and was replaced by autotrophic photosynthesis following the decrease of methane and accumulation of O2 in the atmosphere during the geological evolution of the Earth [10]. The biosphere expanded and occupied pelagic and abyssal zones marked by the appearance of eukaryotes. The volcano-hydrothermal activity and tectonics contributed to nutrient supply and circulation, supporting microbial life. The geochemical trends of bio-essential elements such as Fe, Mn, Mo, P, Ni, Co, and U indicate link between elemental cycling and early life processes [11]. In the modern Earth, the biosphere and anthroposphere exert significant control on the composition of the atmosphere, oceans and the geosphere.

It took over four billion years for the Earth to evolve into a habitable planet and for the birth and evolution of modern life forms. However, the sustainability of the Planet's habitability is currently one of the major aspects of concern for human civilization. This follows the explosive increase in population, depletion of resources, destruction of environment, climate change, natural hazards, and other negative impacts through anthropogenic activities (Figure 2). Energy scarcity and heterogenous distribution of energy-related metals are posing a major global and geopolitical challenge [12–15].

Figure 2. Sustainability challenges of Planet Earth including population explosion, emissions, resource depletion, scarcity of critical minerals for energy transition, and natural hazards, and climate change.

The birth and evolution of Earth and its various internal and external sub-systems form one of the frontier themes of multidisciplinary research. The genesis of mineral resources and their exploration pathways, multidisciplinary aspects of energy-environment-climate-natural hazards, and ultimately the challenges on sustainability and remedial measures are integrated topics to evaluate the past, present and future of the Earth. We therefore launch this new journal, "*Earth Systems, Resources and Sustainability*" [ESRS] as a bridge for scientific investigations on Earth's evolutionary history and its sustainable future. ESRS is an international, peer-reviewed, open-access journal that publishes original research articles and insightful reviews in the multidisciplinary fields of geoscience, geoenvironment, georesources, and sustainability. The Journal is partnered by the International Association for Gondwana Research (IAGR) and published quarterly online by Scilight Press.

This opening issue of ESRS carries six articles with the first article focusing on Inclusive Green Growth as a policy framework for operationalizing Sustainable Development Goals through the Triple Bottom Line. The authors note that adaptability and sustainability of environment and life are under threat. They propose Inclusive Green Growth as an integral component of achieving Sustainable Development Goals. Through a comprehensive bibliometric analysis with focus on the Triple Bottom Line, the study highlights the importance of pluralism and inclusiveness for the harmonious development of economy, environment and society. This study serves as roadmap for enhancing the role of IGG in achieving sustainable and equitable global development.

The next paper on Responsible GeoAI Frameworks for Ethical Governance and Global Sustainability proposes a comprehensive GeoAI framework integrating ethics, skills, and governance. The study addresses the gaps in standardization, transparency, privacy, bias, and accountability and also emphasizes the importance of collaboration among academia, industry, and policymakers to align with the SDGs. It proposes a scalable, responsible, and ethically grounded GeoAI ecosystem for sustainability.

The third paper on Stable Isotopic and Geospatial Approach for evaluating the frequent occurrence of cyclonic events over the Arabian Sea integrates environmental isotopic tracers and geospatial data to investigate the occurrence of cyclones. The authors investigate the hydro-meteorological processes responsible for the genesis and circulation pattern of the cyclone. The study compares the isotopic characteristics and atmospheric processes between the tropical cyclones and the Indian Summer Monsoon. The authors identify that elevated sea surface temperature and anthropogenic forcings are the key factors responsible for the frequent occurrence of tropical cyclones.

The next paper focuses on volcanic hazards and related monitoring of magmatic systems and external forcing. The study offers a novel synthesis of the interplay between endogenous and exogenous processes governing magmatic systems, highlighting how external forces modulate volcanic and hydrothermal activity across spatial and temporal scales. The authors propose a conceptual framework linking external stress perturbations with internal magma dynamics, emphasizing feedback mechanisms during different stages of the eruption cycle. By integrating multi-source geophysical, geodetic, and climatic observations, the study identifies knowledge gaps in understanding how natural forcing affects magmatic inflation, deformation, and eruption forecasting.

The next contribution addresses the current geopolitical issues of natural resource extraction and their implications on sustainable development. Natural resource extraction is one of the important politically consequential and environmentally contentious activities. The authors provide a focused and comparative analysis of how governance quality, institutional design, and global power structures shape the political economy of extraction. They illustrate the convergence or divergence of resource curse, rentier state, and political ecology and attempt to bridge classic resource theories with contemporary green-transition politics and post-extractive development debates.

The sixth and final contribution in this issue reports the mineralogical characteristics of nanocrystalline cookeite from lithium deposit of Jammu, India using employing multi-analytical techniques. This study is the first integrated micro-Raman spectroscopic and nanoscale investigation of the lithium-bearing bauxite from the Reasi inlier in Jammu. The results suggest that kaolinite and cookeite formed through hydrothermal alterations and secondary phyllosilicate formation as a weathering product. Our study contributes to the distribution of lithium minerals which are critical for both resource characterization and the development of effective processing strategies.

The six contributions in the opening issue of this journal illustrate the diverse topics in frontier themes that ESRS covers, in accordance with the aims and scope of the journal in serving as a unique platform, opening new horizons on integrated and interdisciplinary research. We thank all the contributors to this issue and reviewers who provided insightful comments. We look forward to the patronage and support of our scientific community in growing this journal to higher levels of excellence.

Conflicts of Interest

The author declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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