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Elemental Mobility and Provenance in Sediments: A Geochemical Study of Deccan Basalts, Bay of Bengal, and Northern China

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Abstract

Twenty-eight sediment samples from seventeen rivers, including the Krishna headwaters and the west-flowing Western Ghat rivers, draining the Deccan Trap basalts, were analyzed for major elements (Na, Ca, Mg, K, Al, Ti, Fe) and trace elements (Sr, Ba, Mn, P, V, Cr, Ni, Cu, and Zn). The mobility of these elements, especially Na, Ca, Mg, and Sr, was assessed by comparing their abundances in sediments and dissolved phases. Approximately 60% less Na, Ca, Mg, and Sr is present in the sediments compared to the parent basalts, indicating simultaneous release during chemical weathering. K and Ba showed limited mobility, with strong correlations suggesting association in rock-forming minerals. Because secondary minerals are formed during weathering, the sediments are richer in Al, Fe, and Ti. The study also highlights how Fe and Al fractionate during weathering and erosion, with Fe-Ti associations suggesting their resistance to weathering or scavenging by Fe oxy-hydroxides. Minor elements (Mn, P, V, Cr, Ni, Cu, and Zn) show considerable variability in abundance, with zinc potentially influenced by anthropogenic sources. In comparison, major and trace elements from 110 surface sediment samples from the mid-Bay of Bengal were analyzed, indicating intermediate weathering with a Chemical Index of Alteration (CIA) averaging 72.07. Provenance analysis revealed that the sediments primarily originate from Himalayan and Indian sources, with estimated contributions of 83.5% and 16.5%, respectively. Elemental distribution patterns suggest that surface circulation and turbidity currents transport Indian and Himalayan materials across the Bay. Lastly, rare earth element (REE) analyses from a northern China grassland transect revealed variations in REE distributions along an aridity gradient. The study examines the factors influencing REE mobility and fractionation, including climatic and edaphic conditions, to understand how long-range climatic variations affect elemental redistribution in soils.

Keywords: Aridity gradient, Bay of Bengal, chemical weathering, Deccan basalts, geochemistry, major elements, northern China transect, rare earth elements (REE), sediment provenance, trace elements

INTRODUCTION

The study of elemental mobility and provenance in sedimentary environments offers valuable insights into the geological history and compositional evolution of Earth's crust. This geochemical review explores sedimentary deposits sourced from three geologically distinct regions: the Deccan Basalts, the Bay of Bengal, and northern China. Each region provides a unique perspective on sedimentary processes and tectonic settings, shaped by varied histories of volcanism, erosion, and tectonism. The Deccan Traps, one of the world's largest volcanic provinces, exerts a substantial influence on regional sediment composition and elemental mobility, with its basaltic material widely dispersed and undergoing

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extensive chemical alteration. The Bay of Bengal, as a significant depositional basin, receives sediments transported from both the Himalayas and Peninsular India, with contributions modified by intense weathering, monsoonal patterns, and fluvial transport. In contrast, northern China's sedimentary environment is affected by complex tectonic activity and arid climatic conditions, creating distinct patterns of elemental distribution and geochemical signatures.

This review examines elemental mobilization pathways and provenance indicators across these regions to shed light on the processes driving geochemical differentiation, sediment transport, and source-area contributions. These findings underscore the role of regional geology, tectonic regimes, and weathering processes in shaping sediment composition and elemental mobility. Together, the study highlights how sediment provenance analysis can link surface processes with deeper Earth systems, providing a more integrated understanding of crustal evolution and environmental dynamics.

LITERATURE REVIEW

Basalt–water Interaction - River Sediment

The concentrations of major elements (Na, Ca, Mg, K, Al, Ti, Fe) and minor elements (Sr, Ba, Mn, P, V, Cr, Ni, Cu, Zn) were analyzed in 28 sediment samples collected from 17 rivers, including those draining the Krishna headwaters and the west-flowing rivers of the Western Ghats that traverse the Deccan Trap basalts. Key findings for Na, Ca, Mg, and Sr reveal their relative mobility and shed light on the chemical weathering processes affecting Deccan basalts, especially when compared with dissolved-phase data from the same rivers. The sediments contain approximately 60% less Na, Ca, Mg, and Sr than the parent basalts, and the abundance ratios in both sediment and dissolved phases closely resemble those in basalts. This similarity suggests that these elements are released from basalts into the river waters concurrently during weathering, both at present and over the sediments' residence time in the basin.

In contrast, elements such as K and Ba exhibit limited mobility, likely due to their retention in primary rock-forming minerals, as indicated by strong correlations between their abundances. The depletion of more mobile elements from the basalts and interactions with secondary minerals formed during weathering result in higher Al, Fe, and Ti concentrations in the sediments. Fe and Al exhibit fractionation during weathering and erosion, while the correlation between Fe and Ti suggests their association with weathering-resistant minerals and/or Ti scavenging by Fe oxy-hydroxides formed during basalt alteration.

Minor elements (Mn, P, V, Cr, Ni, Cu, and Zn) show substantial variability in both concentration and their ratios to Al, largely within the range observed in Deccan basalts. This variability limits the assessment of their mobility and the extent of potential anthropogenic contributions, though elevated Zn levels may suggest human influence. Minor elements such as Ti, Mn, V, and Ni correlate strongly with Fe, possibly due to co-sequestration by Fe oxy-hydroxides or association with Fe–Ti minerals. The weathering and erosion sequence for Deccan basalts follows the trend: $(Na \approx Ca \geq Mg \approx Sr) > (K \geq Ba) > (Al \geq Fe \approx Ti)$.

The Chemical Index of Alteration (CIA) values of sediments range from 42 to 92, while those of the Deccan basalts average around 37. Lower CIA values in sediments with higher $CaCO_3$ content may reflect the semi-arid climate of the area, which promotes $CaCO_3$ precipitation and reduces weathering intensity. Sediments from basins with greater runoff tend to have higher CIA values, indicating more extensive weathering. Modeling the primary element composition of sediment and dissolved phases in river water yields estimates for particle abundances in water, though these estimates vary by a factor of 3–5 for some rivers while aligning within a factor of 2 for others. Factors contributing to this variation likely include non-steady-state erosion, fluctuations in sediment flux, and the use of sediment composition rather than suspended matter. These factors may also account for discrepancies between CO_2 consumption rates calculated from dissolved-phase data versus those inferred from sediment composition.

Major and Trace Element - Surface Sediment

The distribution of elements reveals that silicon (Si) is the most abundant, followed by aluminum (Al). The sediments in the study area exhibit intermediate levels of weathering relative to those from the Himalayan and Indian rivers, as indicated by an average Chemical Index of Alteration (CIA) of 72.07. Factor analysis and discrimination function analysis suggest that the primary sediment sources are the Himalayas and the Indian Peninsula, with an estimated average contribution of 83.5% from Himalayan rivers and 16.5% from peninsular Indian rivers. An inverse model based on Ti-normalized elemental ratios confirms this, showing a greater Himalayan influence in the eastern portion of the study area, while sediments in the western region show a stronger contribution from the Indian Peninsula.

The primary sediment transport processes in the region include turbidity currents and river-diluted water carrying Himalayan materials, sediment transport via the East India Coastal Current, and surface circulation in the Bay of Bengal. Elemental composition and distribution in the marine sediments are strongly influenced by sediment provenance, hydrodynamic conditions, and grain properties. Elemental geochemistry plays a crucial role in assessing sedimentary environments, and advances in provenance determination have enhanced the accuracy of these studies.

Significant research has focused on the Bengal Fan, one of the largest sedimentary deposits sourced from erosion in the Himalayas and Tibetan Plateau. Previous provenance studies have primarily relied on Sr-Nd isotopic compositions and clay mineral analyses, identifying Himalayan sediments, particularly those rich in illite and chlorite, as major contributors to Bengal Fan deposits. These studies mapped sediment distribution, showing that sediments in the Bay of Bengal predominantly originate from the Ganga and Deccan regions. Specifically, Bengal Fan sediments derive mainly from the Tibetan Plateau and the Himalayas, with Himalayan-derived illite transported by turbidity currents reaching the central Indian Ocean Basin. Regional influences are also evident: Deccan basalt sediments contribute smectite-rich clay minerals to the Krishna-Godavari Basin, Precambrian rocks of the Eastern Ghats contribute illite-rich minerals to the Mahanadi Basin, and volcanic materials from the Sunda Arc affect sediments in the eastern Bengal Fan.

Geochemical studies of Bay of Bengal sediments further support the Himalayas and Tibetan Plateau as primary sources for eastern Bengal Fan deposits, likely influenced by historical variations in monsoon intensity. Quantifying sediment contributions from various sources is vital for “source-sink” modeling, though surface sediment quantification in the Bengal Fan remains limited. Some studies have quantified Himalayan erosion rates using elemental and Sr isotopic data, estimating that 66% of sediment at a central core site originates from the Himalayas, with 34% from peninsular Indian rivers. This study aims to refine understanding of sediment provenance in the mid-Bay of Bengal by mapping provenance distributions, estimating contributions from different sources, and identifying factors influencing these contributions based on major and trace element variations.

Major, Trace and Platinum-Group Element - Greenstone Belt

The early Archean Al-undepleted komatiites (AUK) from Kunikenahalli and Kodihalli, two sites in the Banasandra greenstone band in the Western Dharwar Craton, are analyzed in order to gain a better understanding of their petrogenesis. Their cogenetic nature is indicated by the geochemistry, mineralogy, and field distribution. The majority of the samples are cumulates (MgO: 37–45 wt%), which have fully serpentinized at this point. The spinifex zone is not visible. The MgO content of the primary undifferentiated magma is estimated to be close to 25 weight percent using geochemical modeling. The present study's depleted LREE values, along with earlier research's positive εNd values, indicate that the komatiites originate from a depleted mantle source. The geochemistry of trace elements and PGEs precludes the possibility of sulphide saturation and crustal contamination in these komatiites following emplacement. According to the study's anticipated modeling results, the komatiites would be produced by the melting of about 45% of a deeper mantle (~6 GPa). The mesocumulates found in Kodihalli and the highly fractionated orthocumulates found in Kunikenahalli were created by the fractionation of olivine (Fo94) from the parental melt and their accumulation [3]. It is suggested that the compositional spectrum in the Banasandra greenstone belt, which ranges from Al-enriched (AEK) to Al-depleted (ADK) varieties and is documented in this study and others, is the result of melting a single mantle plume at varying depths.

REE - Arid and Semiarid Grassland

A class of trace elements known as rare earth elements (REEs) exhibit coherent geochemical behavior. When normalized to reference materials, REE fractionation patterns offer a potent tool for recording pedogenesis. It is especially challenging to depict in-soil processes in relation to historical and current climatic conditions. In order to understand the relationships between REE geochemistry components and climatic factors along a large-scale northern China transect (NCT), we characterize the rare earth element (REE) contents in bulk soils and corresponding geochemical fractions (e.g., exchangeable, carbonate-bound, reducible, and oxidizable fractions).

The International Union of Pure and Applied Chemistry (IUPAC) defines the rare earth elements (REEs) as a group of 17 metallic elements. These elements include the elements of the lanthanide series (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu) as well as yttrium (Y) and scandium (Sc). In spite of their names, rare earth elements (REEs) are prevalent and make up approximately 0.015% (w/w) of the Earth's crust, with the exception of short-lived radioactive promethium. For instance, the lanthanide contents vary between 0.5 $\mu g\ g^{-1}$ in Tm and 63 $\mu g\ g^{-1}$ in Ce. With an estimated 1200–1500 kilotons needed globally for expanding applications, rare earth elements (REEs) are also vital for high-tech industries and are widely used in fertilizers to increase crop yields. Due to their shared electrical structure of gradual filling of the 4f orbit, the lanthanide elements (La to Lu) tend to occur together naturally rather than separately and share similar physicochemical characteristics (such as ionic radii, 3+ valent states, and electronegativity). However, different procedures and environmental factors may cause the lanthanides to fractionate. For instance, under oxidizing and reducing redox conditions, Ce and Eu, due to their variable electronic configuration, have a 4+ valent state and a 2+ valent state, respectively. Moreover, the lanthanides are generally divided into three groups: light REE (LREE, from La to Nd), middle REE (MREE, from Sm to Ho), and heavy REE (HREE, from Er to Lu) because of their minor variations in electronegativity. The material circulation of the rock-soil-plant system can be used to magnify and record the effects and geochemical signatures of this fine distinction. The geochemistry of REEs is therefore frequently used to track redox changes in soil, weathering intensities, and parent rock lithology. The REE contents of soil are determined by the weighted average of the abundances of different constituents that include REEs and the concentrations of REEs in geochemical components. The exchangeable fraction, the carbonate-bound fraction (highly mobile and bioavailable), the Fe/Mn oxyhydroxide-affinity fraction (reducible), the organic matter/sulfide-adsorption fraction (oxidizable), and the residue fraction in minerals (less mobile and non-bioavailable) are the five components that can be operationally extracted and separated to demonstrate different forms of REE. It has been shown that variations in edaphic and environmental parameters, such as salinity, pH, redox conditions, and temperatures, affect the mobility and redistribution of rare earth elements into various geochemical components. For example, it has been observed that rising pH and falling redox potential in soils enhance the releases of rare earth elements (REE) from Fe/Mn oxyhydroxide. It is still unknown, though, how long-range climate factors affect the mobility and distribution of soil REE on a continental scale. Suggestive issued two crucial queries: (1) How might various geochemical fractions of rare earth elements in soil change along an aridity gradient? And (2) What ecological and biogeochemical data could those differences offer? Connecting Xinjiang and Inner Mongolia, the Northern China Transect (NCT) is a 3700 kilometer grassland route through northern China. The usual steppe and meadow steppe ecosystem types move from west to east along the NCT, making it a perfect location for studying elemental biogeochemistry along large-scale climate gradients. With a narrowly defined aridity index (AI, the ratio of precipitation to potential evapotranspiration) threshold (AI = 0.20 to 0.30), the nutrient elemental cycling of nitrogen, phosphorus, sulfur, and carbon may be loosely decoupled and tightly coupled across this transect, moving from geochemical to biological control. REE levels and their mobility in soils are correlated with the degree of weathering of parent materials, the storage capacity of authigenic soil phases (such as carbonates, secondary oxide and oxyhydroxide, kaolinite and smectite, and organic ligands), and alterations in redox conditions. Given that the aforementioned factors are influenced by climatic parameters, including temperatures and precipitation, it is plausible to surmise that climate change will have an effect on the mobilization, redistribution, and fractionation of rare earth elements [4]. The objectives of this research are to: (1) measure the geochemical fractions and abundances of rare earth elements (REE) in surface soils; (2) investigate the implications of the relationships between REE abundances and climatic and edaphic factors; and (3) compare the variations in REE distribution in depth profiles to comprehend their possible vertical mobility.

MINERAL GEOCHEMISTRY

Oil and Gas Source - Strata

Typification was done based on the lithological and geochemical properties of the deposits that comprise the sections of the Domanik and Bazhen oil source strata. The lithotypes are disclosed. A variety of laboratory studies involving rocks and contained fluids were conducted for each of the study objects. The mineral content of rocks, the kinds and amounts of organic matter they contained, the maturity level of organic matter, and the chemical makeup of the inorganic and organic components of the study strata were found to be related to one another. The need to evaluate unconventional reservoir rocks is growing as a result of the decline in active hydrocarbon reserves in traditional regions of production, making the study of sedimentary formations—often referred to as black shales and oil and gas source rocks—more pertinent [5]. The US Energy Information Administration (EIA) projects that by 2035, shale oil production will account for 20.5% of global oil production. The production of shale gas and oil has been steadily increasing, accounting for nearly 30% of global hydrocarbon production in recent years, after starting at zero at the beginning of the century. This is evident if you look at the hydrocarbon production in China and the United States. Such objects include oil and gas source deposits of the Bazhenov formation of the Tithonian-Berriasian stages of the Jurassic-Cretaceous systems of Western Siberia (bazhenite) and the Semiluksky horizon of the Frasnian stage of the Upper Devonian of the east of the East European platform (domanikite).

Mineral – Surface Clay

Layer-type aluminosilicates known as clay minerals are involved in the biogeochemical cycles on land, the ocean's ability to act as a buffer, and the containment of hazardous waste. They are also employed as industrial catalysts for the synthesis of numerous organic compounds and as lubricants in the extraction of petroleum. The primary reasons for these applications are the clay mineral particles' colloidal size and persistent structural charge, which give them a high degree of surface reactivity. An ongoing, if difficult, topic in earth science research is figuring out the surface geochemistry of hydrated clay minerals. Recent experimental and computational studies have begun to provide insight into the structure of electrical double layers that form on the surfaces of hydrated clay minerals, particularly those in the interlayer region of swelling 2:1 layer type clay minerals, using new techniques and basic knowledge from studying concentrated ionic solutions. As with a concentrated ionic solution, cation size and charge play a major role in determining how well interlayer cations coordinate with water molecules and clay material surface oxygens. Nonetheless, significant modulations are provided by the presence of hydrophobic patches on the surface of a clay layer and the position of structural charge within it. The influence of clay mineral structure and hydrophobicity on the configurations of adsorbed water molecules increases with the size of the interlayer cation. This picture may be readily expanded to include hydrophobic molecules adsorbed in an interlayer area, which has important implications for clay-hydrocarbon interactions and catalyst design for organic synthesis.

The clay minerals are aluminosilicates of the layer type, which are found in terrestrial weathering environments, marine sediments, and geologic deposits all over the planet. The micrometer-sized particles that they crystallize into are the source of their name. Because of their small particle size, these minerals have a significant surface reactivity that is essential to the chemical homeostasis of the oceans, the terrestrial biogeochemical cycling of metals, and a wide range of regulated processes like the extraction of oil and gas, industrial catalysis, the delivery of pharmaceuticals, and the disposal of radioactive waste. In temperate zone soils, metal nutrients like K+ or Ca2+ are held in reserve on negatively charged clay mineral surfaces. Eventually, these nutrients can be released to be consumed by the biosphere or to buffer the soil from excessive acidity introduced by fertilizers or contaminated rainwater. The global oceanic buffering of atmospheric CO2 and the geochemical cycles of metal cations like K+ can both be impacted by clay minerals that precipitate from seawater in nearshore depositional environments. Petroleum extraction and the building of environmental liners both heavily rely on clay mineral swelling caused by Na+ adsorption in engineered settings. One significant influence on industrial organic synthesis is the wide range of catalysts that have been developed from clay minerals containing adsorbed polymeric cations. Some clay minerals have random isomorphic cation substitutions in their structures, which make them isostructural with mica but less well-crystallized. When clay mineral surfaces are exposed to aqueous electrolyte solutions, or natural waters, these cation substitutions produce a negative net surface charge that causes an electrical double layer to form on the mineral surfaces. An interlayer ionic solution resulting from the intercalation of water molecules between clay layers can induce swelling phenomena associated with electrical double layer properties. Much geochemical research has been done on the structure of the double layer that forms in swelling clay mineral interlayers, but only recently, with the help of knowledge gained from studying concentrated aqueous ionic solutions, has the potent tandem mix of spectroscopy and molecular modeling been able to shed light on the situation [6]. Isotope-difference neutron diffraction and Monte Carlo computer simulation have proven to be two particularly successful innovations. This subject provides a brief overview of our recent work on the hydrated clay minerals, which play a major role in terrestrial surface geochemistry, using these two innovations. The focus of this study is on the molecular picture of the interlayer structure of clay hydrate, specifically examining the similarities and differences between this structure and that of concentrated ionic solutions and the tetrahedral hydrogen-bonded network that characterizes liquid water in bulk. A deeper understanding of these fundamental concepts is necessary to better model the global elemental cycles and create engineered clay materials.

Chemical – Microbe

Located in Chiapas, Mexico, the "Lagunas de Montebello" National Park is renowned for its blue waters. However, some of these waters began to lose their clarity in 2003 and turned hazy brown instead. They also occasionally emitted an unpleasant odour and contained dead fish and white-yellow sediment debris. A physicochemical characterization of the first six meters of the water column, a geochemical speciation analysis, and the calculation of the saturation index for various minerals were carried out in order to identify the reasons behind the variations in the water characteristics of the Montebello lagoon system's "Liquidambar" lagoon.

Rock dissolution was identified as the primary mechanism governing the chemistry of water, which was classified as calcium-sulfated. At every depth in the range of 0.11 to 1.13 mg/L, sulfur was discovered. The water column's sulfate concentration varied from 249.21 to 298.7 mg/L, the range of carbonate was 140.5–261.4 mg/L. The range of magnesium, and calcium was 94.5–146.9 mg/L as well as 34.2–38.3 mg/L, respectively. Similarly, it was discovered that the surface of oxygen had an oversaturation value of 9.32 mg/L. The mineral phases dolomite, aragonite, and calcite were shown to be oversaturated, with a higher saturation level on the surface, based on the results of speciation and SI. The findings raised the possibility that the turbidity, color shift, and white supernatant were caused by carbonate mineral precipitation, which was influenced microbiologically by photosynthetic activity in the lagoon's uppermost layer. Geochemistry examines how elements and compounds are redistributed in both natural and man-made environments. It also examines the mechanisms governing the chemical composition of water. These processes are identified by analysing the physicochemical parameters of the water, which enables the identification of qualities, origins, types of rocks the water flows through, flow patterns, and even the length of time the water spends in the watershed and aquifers as a result of its interaction with geological mediums. The three primary mechanisms that regulate the chemistry of water are evaporation, dissolution of crustal minerals, and atmospheric precipitation. Other mechanisms that affect the chemistry of water include chemical reactions, like the dissolution of silicates, which calls for acid-base reactions, and redox reactions, the majority of which are supported by biology. These reactions have a major impact on elements like O, C, S, N, and Fe. Water chemistry is also influenced by processes such as ion exchange and absorption [7]. Rapid processes governed by chemical equilibrium include ion exchange, precipitation, and mineral dissolution. Conversely, kinetics governs the slow processes of redox transformations and silicate dissolution. The processes mentioned above primarily produce the following water solutes: Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, HCO^{3-}, Cl-, SO_4^{2-}, and H_4SiO_4.

Auriferous Deposit – Tailing

Since the middle of the 19th century, metallurgical facilities in Nova Lima, Brazil, have been processing gold ores, which are primarily found in sulfides.

Over time, the produced wastes have gathered in piles or tailings dams. These materials are leftovers from both operating plants and outdated circuits. To assess their potential for reuse, wastes from geochemical, mineralogical, 3D modeling, and metallurgical analyses were examined in this study. The characterization process found extremely fine-grained residues containing oxides and sulfides. High grades of Au are present in the wastes, hosted in various minerals. Samples also include S, Fe, Zn, Pb, Sc, Si, and As in addition to Au. Using dimensional variograms and ordinary kriging, 3D modeling was carried out for the purpose of defining the spatial definition of Au. The findings made it possible to identify the most desirable tailing deposits in terms of Au content and demonstrated the existence of Au enrichment zones. Metallurgical testing revealed that 70% of the Au could be recovered, and other possible uses for the wastes were mentioned, including the recovery of other metals and aggregates for the civil construction industry. The current study emphasizes the value of tailings in the mining industry's supply chain and the significance of an integrative characterization within the framework of the circular economy. One of the most significant industries in Brazil both economically and socially is mining. Currently, this industry accounts for three to five percent of the GDP. This economic sector has been important since the start of the first gold cycle in the seventeenth century. Brazil produced about half of the world's gold in the middle of the eighteenth century, which led to the immigration of about 400,000 Portuguese people, mostly to the Nova Lima region of Minas Gerais. Currently, this industry provides raw materials to a number of other industries, including the aerospace, automotive, and construction sectors. Sustainable development is still hampered by the production of plentiful tailings materials, despite its strategic and pertinent importance to the economy. Over 500 million tons of mining waste are recorded in the State of Minas Gerais. Dams and mine dumps—of which there are more than 500 documented instances in the state, at least 15 of which are related to gold mining—are the primary infrastructures utilized for the deposition of these wastes. The environmental and population risks associated with dams and mine dumps are exemplified by the tragic dam collapses that occurred in the Brazilian states of Minas Gerais' Brumadinho and Mariana regions. The production of mining waste coupled with potential supply disruptions and limited replacement, and consequently, disruptions in the supply of essential substances, can have detrimental effects on all parties involved, both directly and indirectly, and have an impact on the global socioeconomic system. These wastes, however, might be considered mineral deposits that differ from the mined primary ore in terms of physical attributes and grade. Mine wastes frequently contain intriguing concentrations of materials that are essential to today's technological society. The EU developed the Critical Raw Materials list as a result of this criticality. Key components with economic significance and supply risk are included in this list. Furthermore, materials like Au that are in high demand and are used continuously are also highlighted. It follows that there is an unquestionable need for thorough research on these kinds of waste. Numerous approaches have been investigated by researchers worldwide to address the problem of solid mining tailings formation. There are several routes that try to strike a balance between the tailings exposure and the interests of the social, economic, and environmental sectors. These include recycling and repurposing waste in a variety of ways, which results in proactive waste management. These models seek to increase the value of tailings by determining where potentially hazardous materials should be sent. Research employing an assortment of characterization methods serves as the foundation for enhancing these wastes' worth and expanding our understanding of them. Numerous publications show how analytical techniques like density determination, mineralogical and particle size distribution, and specific chemical analysis for solids are integrated, indicating how important this characterization stage is to assessing and comprehending the waste deposits.

The use of mathematical and geostatistical tools, which are commonly employed in the numerical definition of mineral deposits, is highly beneficial for tasks such as sampling grid definition, modeling the distribution of grades, tonnage, and contaminants dispersion patterns of tailings, among others. Numerous case studies that make use of mathematical methods are documented in scholarly works. Usually, they integrate statistical tools with waste characterization to obtain models for the valorisation potential and to better understand the environmental implications of the mine dumps. As a result of these advancements in characterization, market trends, and technological advancements, these wastes can offer an alternative to primary exploitation and support the long-term sustainable growth of the mining industry in the area. A reuse study based on waste characterization and statistical factors is a crucial step in assessing and comprehending the economic potential of these secondary deposits. Processing of all waste types and forms, from solid to gaseous phases, is covered in this phase. At this point, several kinds of proposals can be explained. The recovery of base elements from acidic drainage solutions in abandoned mining waste dumps, the recovery of metals from dam water, and the reuse of solid tailings with the recovery of valuable and vital elements for society are a few examples of these techniques.

Various approaches were suggested for recovering Au from secondary sources in relation to the tailing's deposits left over after treating Au ores. Au recovery from tailings deposits appears to be facilitated by the combination of hydrometallurgy, pyrometallurgy, biological agents, and geochemical and mineralogical characterization techniques [8]. In addition to these evaluations and approaches, the state-of-the-art shows success in extracting gold from mine tailings through a variety of procedures. Nevertheless, because they contain potentially dangerous materials, dams and tailings deposits have an impact on the environment. In other words, the possibility and interest in this study are supported by the difficult and contradictory aspects of the massive amount of trash and the considerable risk to human health and the environment [9, 10].

CONCLUSION

The geochemical study of sediments from the Deccan basalts, Bay of Bengal, and northern China illustrates the interplay of source material, weathering, and tectonic influences on elemental mobility and sediment provenance. Deccan-derived sediments exhibit a unique trace-element signature influenced by extensive basalt weathering, while the Bay of Bengal's depositional environment reflects Himalayan contributions modified by intense chemical alteration. Northern China's sediments highlight the impact of diverse tectonic settings and arid climate on geochemical patterns. Together, these findings emphasize the importance of provenance studies in understanding sedimentary processes and Earth's geological history. Future research should explore the impact of climatic shifts, tectonic reconfiguration, and anthropogenic influences on sediment composition, providing a more comprehensive view of sedimentary dynamics and elemental mobilization across various depositional systems. This review underscores the value of integrating geochemical data with regional geological context to unravel the complexities of sedimentary provenance and environmental evolution.

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