GOVERNMENT OF INDIA
MINISTRY OF
MINES

Policy for Exploration of Critical Minerals in New Projects and Recovery of Critical Minerals from Overburden, Dumps and Tailings of Existing Mines, 2025

Ministry of Mines
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1.0 Introduction

1.1 Minerals are a valuable natural resource being the vital raw material for the core sectors of the economy. Exploration, extraction and management of minerals have to be guided by national goals and perspectives, to be integrated into the overall strategy of the country's economic development. Endeavour shall be to promote domestic industry, reduce import dependency, and feed into Make in India initiative.

1.2 The National Mineral Exploration Policy (NMEP), 2016 spells out the strategy and outlines the action plan that the Government will adopt to ensure comprehensive exploration of country's mineral resources (non-fuel and non-coal) including critical minerals. Successful exploration requires the bringing together of the best of knowledge and experience, the state-of-the-art technology, highly trained manpower, and also enormous financial resources, on an open, collaborative and inter-disciplinary platform.

1.3 The National Mineral Policy, 2019 of Government of India in Para 6.2 has spelt out a concept of zero waste mining with an intent to recover all the possible minerals commodities including critical minerals during mining and processing stage.

1.4 In order to ensure supply chain resilience of critical minerals and to meet net zero target, Ministry of Mines, Government of India has introduced a new list of Critical and Strategic Minerals in Part 'D' of the First schedule of the Mines and Minerals (Development and Regulation) Act, 1957 on 9.08.2023. The list of these minerals is enclosed as **Annexure-I**. Some of these minerals can be found and extracted independently such as glauconite, graphite and potash but many of the other minerals/elements are found as an associate or companion metal along with the primary mineral and are produced while mining and processing of these primary minerals.

1.5 Under the National Critical Mineral Mission (NCMM), one of the main components is increasing domestic critical mineral production and recovery of critical minerals from overburden, tailing, fly ash or red mud is a sub component of it.

1.6 Further, NCMM envisages that the regulatory regime will be relaxed to encourage optimum recovery of critical minerals from various sources such as overburden, tailings, fly ash, red mud, existing mines etc. Moreover, as several critical minerals are associated with major minerals, the Government will design a lower revenue share for critical minerals associated with major minerals. To promote the ecosystem, the government will also ensure setting up pilot projects for mineral recovery through novel methods by encouraging collaborations between industry, academia and research institutions.

1.7 Realizing the potential of these tailing dumps which could be hosting a lot of critical or strategic minerals essential for the modern-day technologies, Hon'ble Union Finance Minister in her 2025-26 Budget Speech announced to bring out a policy for "recovery of critical minerals from tailings".

2.0 Need for a Policy

2.1 Historically, mining operations in India and around the world focused primarily on extraction of one or two primary commodity that were easy to recover and profitable, such as gold, silver, iron, copper, lead and zinc. Many of these primary commodities also contain with them other elements such as cadmium, vanadium, gallium, tungsten etc. commonly referred to as companion metals. The companion or associated elements occurring with these primary commodities were not recovered due to technological or economic limitations. Many of these elements, which were once unrecoverable and left in tailing ponds/dumps, are now classified as critical and strategic minerals, crucial for sectors such as electronics, renewable energy, and defence.

2.2 With the advancement of mining and processing technologies, and depletion of high-grade ores, cutoff grades for mining and processing the run off mine ore (ROM) have been revised downwards over the years. Materials once deemed uneconomic and discarded as waste in waste dumps and mine tailing now offer renewed promise. These dumps, located both at active and abandoned mine sites, could serve as potential secondary source of valuable minerals.

2.3 Thus "tailings" may be defined as that slurry of fine gangue materials generated during processing and refining of the ROM after recovery of the target minerals. The tailings are stored in tailing ponds. In India, the tailing ponds are mainly found associated with mining of ores such as copper, lead & zinc, gold, bauxite, rock phosphate, graphite, chromite, uranium, iron ore, and coal washeries.

2.4 Few of the commodities currently mined in India as primary ore may have scope for recovery of various companion metals/ elements from the tailings, anode slimes, pot linings and slags which are tabled below:

Table showing the Primary commodity and likely companion elements in India

Primary Commodity	Companion elements
Copper	Selenium, Tellurium, Molybdenum, Cobalt, Rhenium, Gold, Silver

Zinc	Germanium, Silver, Cadmium, Indium
Lead	Silver, Antimony, Bismuth
Aluminum	Vanadium, Gallium
Manganese	Cobalt
Gold	Silver, Tungsten, Copper, Zinc, Antimony
Chromite	Nickel, PGE
Tin	REEs, Niobium, Tantalum and other critical and strategic elements,
Graphite	REEs
Uranium	Copper, nickel, cobalt and molybdenum
Coal	Cobalt, nickel, and REEs
Crude Oil	Vanadium, Nickel

2.5 Based on above analysis, various sources in which specific critical minerals can be found in any of the below secondary source need to be identified:

a) **Waste dump**: unlikely to have any valuable economic minerals worth recovering for further use. However, in certain cases these dumps may contain some critical elements. (Nickel & PGE in Chromite mine dumps).
b) **Sub grade/mineral reject dump**: material may be either grade or size reject and may have future economic value due to technological changes and market dynamics.
c) **Tailing dams/dump**: Tailings are fine-grained waste material that remains at the tail-end of the mining process once desired metals and minerals are isolated from ore deposits. These tailings contain significant values of other critical elements which occur with the primary metal as companion metals. They may also serve for reworking of the primary commodity.
d) **Smelter slag dump**: Residue generated after smelting and recovery of primary metal. May be an important source for other critical elements.
e) **Anode slime**: Anode slime, pot linings also are possible source of some critical elements.

2.6 As may be observed from the above, the occurrence of critical & strategic elements is not only restricted to the solid mineral resources under the administrative control of Ministry of Mines but may also be available in other commodities which are being dealt by various other ministries. Therefore, a coordinated approach among various ministries is essential to identify the location of all the tailing ponds and dumps, their quantity and likely availability of various critical and strategic elements. Based on this, the recoverability and economic viability of these tailings can be evaluated. It is therefore essential that organizations like Indian Bureau of Mines

(IBM), Central Mine Planning & Design Institute (CMPDI) and Atomic Minerals Directorate of Exploration & Research (AMD) conduct systematic sample analysis of dumps, and tailings of all existing mines to arrive at companionality to identify the location of all the waste dumps, overburden, subgrade dump and tailing ponds their quantity and likely availability of various critical and strategic elements. Hence, the need for this Policy.

3.0 Policy actions to promote to discovery/recovery of critical minerals from all value chain including tailings

The policy governing discovery and recovery of critical minerals from all value chain including initial exploration, overburden, existing mines and processing operations, tailing in the country shall essentially include the following actions:

3.1 Exploration:

The occurrence of critical minerals as companion metals and elements are required to be identified right from the exploration stage itself. All new exploration projects shall ensure that all elements are identified and all core data are examined and maintained to verify all elements using latest technology based on companionability. The heterogeneous nature of mineral deposits necessitates standardized methodologies for sampling, analysis, and data reporting to ensure accuracy, consistency, and comparability. Therefore, following actions are proposed to be undertaken:

A. A uniform protocol is proposed starting from reconnaissance survey to advance stage of drilling covering sample collection, preparation, and analytical techniques. Therefore, all the agencies carrying out the exploration in the country must adhere to the 'SOP of Mineral Exploration' issued by GSI for both bulk minerals and non-bulk minerals (**Appendix I**).

B. The projects funded through NMET funding shall also follow guidelines issued by GSI to detect presence of all elements in host rocks.

C. All exploration agencies should carry out analysis of all core data available to identify the critical minerals in a time bound manner.

D. Systematic identification of trace elements (e.g., Ge, Li) and Rare Earth Elements (REE) during coal exploration is imperative to preemptively mitigate mineral loss to tailings and unlock strategic resource potential. CMPDI in association with GSI has framed similar guidelines for chemical analysis for detecting presence of critical minerals in host rocks of coal and lignite. (**Appendix II**).

E. Like major minerals, association of critical minerals with the minor minerals may also be assessed along with their availability in the dumps generated during mining operations involving minor minerals. GSI has framed a Standard Operating Procedure (SoP) for assessment of Critical Minerals during exploration of Minor Minerals and from their mine dumps which will be followed by the States. **(Appendix III)**.

F. The critical minerals also occur in similar geological setting which contains the atomic minerals. Therefore, it is imperative to look for occurrence of critical minerals while carrying out exploration of other atomic minerals. The Atomic Minerals Directorate for Exploration and Research (AMD) being an exploration agency as well as the regulatory authority in respect of atomic minerals has framed guidelines for analysis for assessment and evaluation of associated elements at the different stages of exploration as well as in existing operational mines. **(Appendix IV).**

G. Ministry of Petroleum and Natural Gas may also frame guidelines for analysis for detecting presence of critical minerals at the time of exploration and share the information with Ministry of Mines for taking up further exploration. Oilfield brines are limited to reservoir pore spaces. Exploration for critical minerals throughout the basins can augment the resource of critical minerals.

3.2 Analysis for detecting presence of companion minerals in operating mines/ dumps/ tailing ponds:

IBM has prepared a SoP on sample collection from mines and tailings which is attached at **Appendix V**. Similarly, detailed sampling and analysis of coal bearing areas also needs to be taken up. A SoP detailing the same is attached as **Appendix VI**. GSI has also framed the SoP for assessment of Critical Minerals in the mine dumps for minor minerals **(Appendix III)**. The AMD has also prepared a SoP for analysis for assessment of associated elements in existing operational mines which is included in **Appendix IV**.

The inventory of the mine dumps/ tailing ponds may be maintained by agencies under Ministry of Mines, Ministry of Coal, Department of Atomic Energy in a GIS based platform for easy accessibility and operability. These databases may be utilized for systematically cataloguing, further sampling and identification of critical minerals in the mine dumps/ tailing ponds. The data so generated may also be extended to exploration agencies like GSI, MECL, private agencies for carrying out exploration of critical minerals in the areas extending beyond the mining lease areas. The inventory of these databases may be put in public platform as far as feasible.

A coordinated approach among ministries is proposed to create a centralized database of all the tailing ponds/ dumps including those which are **abandoned**. The location, nature (dry/wet), operating/ abandoned, commodity, quantity and quality of these tailings are required to be systematically catalogued. Tailing ponds which are located or operated by person other than the mineral concession holder will also be included in the list. IBM may create a GIS-linked record of every tailing dam, waste-dump, beneficiation slime pond and red-mud stack pond in the country, with grade, tonnage, chemistry and hazard rating.

3.3 Enabling law to facilitate mining of companion minerals and providing incentives to produce companion minerals:

Under the MMDR Act and the rules made thereunder, a mining lease is issued for mining of specific minerals. As per the existing rules, associated minerals discovered in the leased area of auctioned mines can be included in the mining lessee and lease holder may win and dispose of such mineral on payment of auction premium quoted at the time of auction. For non-auctioned, the inclusion of associated minerals discovered in the lease area is prohibited.

Absence of a provision for inclusion of associated mineral in non-auctioned mining lease and payment of high premium by auctioned mines for associated minerals leads to locking such deposits and sub-optimal mining or non-reporting of the presence of such mineral by the lessee. Accordingly, the MMDR Act, 1957 has been amended in August 2025 to provide a simpler regime allowing inclusion of any companion mineral in a mining lease. In case the included companion mineral is a critical and strategic mineral listed in Part D of the First Schedule to the Act or a mineral listed in Seventh Schedule to the Act, the miner will only pay applicable royalty on them and no additional payment or auction premium will be applicable in such case.

3.4 Facilitating EC for extracting companion minerals: Extraction of companion minerals may attract additional EC requirements. Since recovery of critical minerals is done from the ROM, which is already counted as part of the production limit under EC, there should not be any requirement to obtain EC if it is within the mining lease area. This will facilitate the recovery of critical minerals in the interest of mineral development.

3.5 Research and Development: A component for domestic and international Research and Development (R&D) has been provided under the NCMM, which can be utilized for developing technologies for the extraction of critical minerals from tailings.

4.0 Conclusion: Critical minerals, including lithium, cobalt, nickel, Rare Earth Elements (REE), etc., are vital for technologies like solar panels, wind turbines, batteries and are essential for India's economic growth. India's focus on self-reliance and green technologies is driving the need to secure domestic supplies and resilient global supply chains for these minerals. Therefore, the primary focus of the exploration agencies in the country has shifted from exploration of bulk minerals to exploration of critical minerals. Further, the overburden, tailings, red mud, existing mines dumps, etc. are important secondary sources for critical and strategic minerals in addition to the primary sources. A comprehensive, systematic and coordinated approach is required for identification and resource evaluation of the critical minerals occurring in various sources during exploration as well as during the exploitation stage involving agencies working in Coal, Non-Coal, atomic minerals and Petroleum Sector.

Hence, the present tailing policy will serve as a standard guideline for tapping these critical minerals from primary as well as the secondary sources. In addition, this Policy will also help in framing a roadmap for the recovery of these critical minerals once they are identified in the tailings, dumps, mine wastes, etc. The recovery of these critical minerals from the primary and secondary sources will ensure increased domestic production, reduced import dependency, reinforce supply chain resilience, increasing India’s self-reliance in these minerals.

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Annexure I

PART D of the First Schedule of the MMDR Act, 1957 (amended 2023)

Critical and Strategic Minerals

1. Beryl and other beryllium bearing minerals.
2. Cadmium bearing minerals.
3. Cobalt bearing minerals.
4. Gallium bearing minerals.
5. Glauconite.
6. Graphite.
7. Indium bearing minerals.
8. Lithium bearing minerals.
9. Molybdenum bearing minerals.
10. Nickel bearing minerals.
11. Niobium bearing minerals.
12. Phosphate (without uranium).
13. Platinum group of elements bearing minerals.
14. Potash.
15. Minerals of the "rare earths" group not containing Uranium and Thorium.
16. Rhenium bearing minerals.
17. Selenium bearing minerals.
18. Tantalum bearing minerals.
19. Tellurium bearing minerals.
20. Tin bearing minerals.
21. Titanium bearing minerals and ores (ilmenite, rutile and leucoxene).
22. Tungsten bearing minerals.
23. Vanadium bearing minerals.
24. Zirconium bearing minerals and ores including zircon.

Appendix I

Standard Operating Procedure (SOP) for Exploration of Non-Coal and associated rocks for exploration of Critical and Strategic Minerals

1. Introduction

Globally Mineral exploration practices vary significantly owing to the unique geological characteristics inherent in each mineral deposit. The distinct geological, geochemical and geophysical features of every mineral deposit necessitate tailored exploration strategies, dynamically evolving as the exploration progresses. These tailored strategies must be formulated based on comprehensive preliminary findings derived from meticulous pre-field studies. Recognizing these complexities, the following guidelines offer generalized yet adaptable procedures and responsible practices for conducting mineral exploration, especially for critical minerals.

2. Geological Milieu and associated mineral systems

Establishing a robust geological understanding is crucial and pre-requisite, as it enables accurate identification of potential mineral targets. However, targeting a mineral deposit is also dependent on the understanding of the mineral system that is being considered. A mineral system comprises all the geological elements and processes that lead to the concentration of valuable metals or minerals, including the source of the metals, the pathways for fluid and metal transport, the trap where physical and chemical conditions facilitate deposition, and subsequent preservation of the deposit. This integrated approach allows geologists to identify favourable regions for exploration by recognizing the characteristic footprints of mineralizing systems, looking beyond simply searching for individual ore bodies to understanding the fundamental geological architecture that controls their existence. There are varied views worldwide about the minerals system. But it can be broadly classified into three major categories that cover majority of the deposit types related to critical mineral where each broad class has a unique elemental signature that guides exploration. However, it may be noted that exception of these broad classes can also exist in nature which could represent a potentially unique deposit type.

2.1 Magmatic Mineral System

The magmatic mineral system is characterized by the direct concentration of metals from a silicate melt through magmatic processes such as crystal fractionation, immiscibility, and accumulation in large igneous bodies. These systems typically form from high-temperature igneous processes in tectonic settings associated with mantle-derived magmas, continental flood basalts, alkaline intrusion, layered mafic-ultramafic intrusions and evolved pegmatitic intrusion. One of the key features of this system is the presence of igneous host rocks and metal enrichment via sulphide or oxide segregation.

The magmatic systems host Ni-Cu sulphides, Platinum Group Elements (PGE), chromite (Cr), and titanium (Ti) minerals, and can contain Rare Earth Elements (REEs), Mo associated with carbonatites, granites etc.

2.2 Hydrothermal Mineral System

Hydrothermal mineral systems form through the circulation of hot, mineral-rich fluids within the Earth's crust, often associated with magmatic activity, metamorphism, or deep-seated fault structures. These fluids, heated by various geological processes, leach metals from source rocks and transport them through permeable pathways like fractures and shear zones. Ore deposition occurs when changes in temperature, pressure, pH, or redox conditions cause the dissolved minerals to precipitate, leading to the formation of diverse deposit types such as porphyry, epithermal, and vein-type deposits. The specific characteristics of the fluid, its interaction with wall rocks manifested as alteration zone of varied dimension, and the structural controls ultimately dictate the size, grade, and mineralogy of the resulting ore body.

The hydrothermal systems are responsible for a wide range of economically significant deposits, including porphyry Cu-Au-Mo, epithermal Au-Ag, skarn Fe-Cu-Zn, vein-type Pb-Zn-Ag-Ge-Cd; REE-Nb-Y-Ta-Li-Rb, Sr hosted in pegmatite, greisen related Sn-W deposits, and basinal hydrothermal mineral systems (such as Zambian-type Cu-Co systems, SEDEX Cu-Zn-Pb systems, MVT Pb-Zn-Ba systems etc).

2.3 Sedimentary and Regolith hosted mineral systems

Sedimentary and regolith-hosted mineral systems represent important pathways for the formation and concentration of critical minerals through exogenic processes, viz. physical, chemical, and biological processes acting within sedimentary basins over extended geological time. These systems are influenced by depositional environments, basin architecture, and tectonic settings, resulting in a diverse range of mineral deposit types. Key examples include:

- *Modern and Palaeo-placer Au-U systems* (e.g., Witwatersrand, South Africa), formed through the mechanical concentration of dense minerals in ancient fluvial or marine settings where gold and other heavy minerals such as zircon, monazite, allanite, rutile etc. are hydraulically sorted and deposited in riverbeds or beaches.
- *Evaporite-hosted systems,* found in closed-basin playas or salars in arid regions, e.g., the Lithium Triangle in South America), where lithium is enriched in saline water through evaporation, and Evaporite type potash deposits of Nagaur-Ganganagar sub-basin of Rajasthan.
- *Sedimentary Phosphate deposits* are also significant sources of Phosphorous and occasionally associated REEs such as reported from Morocco and China.
- *Graphite mineralization* associated with meta-sediments also represents a sedimentary mineral system. While the graphitization process itself is a result of metamorphism, the original accumulation of organic carbon, which is crucial for graphite formation, is fundamentally attributed to sedimentary processes. Vanadium is often closely associated with such deposits.
- *Regolith-hosted mineral systems* developed through intense chemical weathering of rocks in tropical to subtropical climates, often over millions of years, leading to deep weathering profiles and the residual concentration of economically valuable metals.
    - Critical minerals associated with regolith-hosted systems include Ni, Co, REEs, Li, Ti, V, Ga and Sc.

    - These systems are increasingly important for future resource development due to their surface accessibility and potential for low-cost extraction. These include lateritic nickel-cobalt deposits, where Ni, Co, Ti, V, Sc are concentrated in oxide and clay zones from weathered mafic-ultramafic rocks, and Ga in bauxite deposits, the primary source of Al. Similarly, ion-adsorption REE deposits develop when REEs from weathered granites become weakly bound to clays, particularly significant for HREEs. Other surficial deposits encompass calcrete-hosted uranium, precipitating in arid calcareous soils, and residual lithium along with associated critical elements like Be, Cs, and Rb, which accumulate in clay-rich profiles derived from weathered granitic or pegmatitic terrains.

Nature of mineral systems	**Associated critical minerals to be analysed**
Magmatic Systems	• Ni-Cr-PGE-Cu-Ti-V in mafic-ultramafic • REE-Nb in carbonatites, alkaline complexes • Mo, Nb, Y, Sc, Li, Be, Cs, Sr and Ta in pegmatites and granites
Hydrothermal systems	• Orogenic Au, carlin type Au • Cu-Mo-In-Te in porphyry • Basinal hydrothermal o Zambian-type Cu-Co o SEDEX type Cu-Zn-Pb-Cd-Ge o MVT type Pb-Zn-Ba • Cu-REE-Fe-Au in IOCG • P±LREE in Kiruna type
Sedimentary and Regolith-Hosted Mineral systems	• Evaporitic Li-brine and Potash • Limestone, iron ore, sedimentary phosphate associated to limestone, Glauconite associated to sandstone-shale-limestone • Graphite-V in meta-sediments • In-land Placer and Paleo-Placer for Au-REE • Ti-REE-Zr beach sand placer • Lateritic/bauxitic Ni-Co, Ga, Sc, Ti, V, REE accumulations in regolith • REE, Lithium and associated elements in residual clays/laterite.

3. Mineral Exploration – Best Practices

Mineral exploration needs to be conducted through a structured and systematic phased approach that allows assessment of the geological potentiality and economic viability of mineral deposits while adhering to environmental and regulatory standards. Therefore, a phased exploration strategy that provides a framework for identifying, assessing, and advancing mineral prospects toward development is provided in this section of the document.

3.1 Phase-I

Pre-field Studies

The stepping stone of the phase is collation and logical analysis of all available legacy data including geological maps, exploration reports, satellite imagery, geophysical datasets, scholarly articles or any other relevant information. The available multi-faceted datasets can be utilized in GIS platform-based data analysing software for detailed multi-source data integration and precise targeting.

- Gathering all the available remote sensing data such as Landsat, ALOS and Google earth imageries also needs to be done for desktop study of these images. Thereafter a base map of the region or area needs to be prepared by overlaying this satellite image/s on topomap (1:25,000 and 1: 50,000). The base map must have geographic coordinate grids with certain grid interval depending on the size of the study area.
- Derivative maps of available regional (NAGMP, NGPM) and prospect scale geophysical data are to be used to produce different derivative maps such as Reduced to Pole (RTP) to understand subsurface disposition of lithologies and structures. Inversion of regional gravity can be attempted to determine the possible lithology, dimension and depth of occurrence of the causative anomalies.
- Regional geochemical data such as NGCM or other data from geochemical prospecting are to be used for geostatistical analysis to estimate the threshold, anomalous concentrations and outliers. To generate elemental distribution maps statistical interpolation methods such as krigging along with semi-variogram models are to be adopted to narrow down on the target area for initial exploration.
- Structural data are to be analysed to delineate zones of major faults, shear zones, hinge zones and axial traces of regional scale folds that can either act as pathways for mineralised fluid migration or zones of accumulation of the mineralisation and to decipher the geometry of the ore body. Available Geophysical data are also to be utilized to understand the subsurface continuation of the interpreted structures. Inversion modelling of regional data is to be done to determine the subsurface architecture. Satellite imagery such as Sentinel or other high-resolution imagery can be used to delineate major structural lineaments to establish their relationship with regional structures and possible sequence of tectonic evolution in the targeted area.
- Alteration mapping using satellite hyperspectral and ASTER data is a crucial remote sensing technique in critical mineral exploration. These datasets, by capturing reflected electromagnetic radiation across numerous narrow spectral bands, allow for the identification of specific mineral assemblages associated with hydrothermal alteration zones. Minerals like clays (e.g., kaolinite, illite), micas (e.g., sericite), carbonates, and iron oxides exhibit distinct spectral signatures that can be detected and mapped, providing proxies for underlying mineralization. This approach enables rapid, cost-effective, and large-scale preliminary targeting of prospective areas, especially in remote or challenging terrains, significantly narrowing down the ground exploration focus for critical minerals.
- Distal foot-printing for critical mineral exploration involves detecting geochemical or hydrogeological anomalies at significant distances from the actual mineralized zones, offering a cost-effective and non-invasive reconnaissance tool. Groundwater sampling is a key method, as circulating waters can mobilize and transport trace elements or pathfinder ions (e.g., Li, REEs, Co, Cu, Sb, As) from hidden mineral systems, often leaving detectable signatures in surrounding aquifers. This approach can be complemented by analysing

stream sediments, secondary minerals in overburden. Integration of these indirect signals with hydrogeochemical modelling can enhance the ability to vector toward buried or blind deposits, especially in covered terrains or deeply weathered profiles.

- Similarly, focus is to be exerted on the geological environments/set-ups favourable for critical mineral deposits such as pegmatitic lithium, lateritic cobalt-nickel, and carbonatite-hosted REEs.
- Interpretation of regional-scale tectonic, structural, and stratigraphic analyses is essential to effectively identify target commodities and their favourable geological domains. For instance, a subduction-zone setting would warrant a greater focus on porphyry-type Cu-Mo-Au±Ag mineral systems within the overriding plate, whereas areas with lateritic or regolith cover should direct exploration toward secondary enrichments of REEs and Rare Metals. Interestingly, exploration strategies would be different in these two cases.
- For assessing bedded deposits, such as phosphorite in limestone, glauconite in sandstone/shale, iron ore or critical elements like Ga, Sc in bauxite, systematic compilation and detailed evaluation of legacy data is essential. Spectral analysis of satellite imagery, integrated with historical geochemical datasets, effectively delineates anomalous zones for glauconite-bearing sandstones/shales and bauxite occurrences. Additionally, integrating available data on sedimentological studies further aids in identifying favourable lithological sequences indicative of potential mineralization.

3.2 Phase-II

Reconnaissance Surveys (G4 stage Exploration)

The primary objective of this stage of investigation is to determine the anomalous concentration of the critical minerals and establish the dimension of the mineralised body. Initial site inspections are required to verify geological interpretations derived from remote sensing and pre-field studies.

- A Large-Scale Geological Mapping (LSM) at appropriate scales, preferably on 1:12,500, depending on the targeted commodity is to be carried out. For example, tungsten-bearing veins of smaller dimensions and limited continuity necessitate detailed mapping at a larger scale, while large, extensive carbonatite/alkaline complex hosted REE deposits can be effectively mapped at scale of 1:12,500.
- For targeting Regolith hosted secondary enrichment of critical mineral, the nature of Regolith, i.e., whether residual or transported is to be established using combination of satellite imagery and field inspection. The map of Regolith cover is to be developed accordingly as per the international RED code. The areas with residual Regolith covers are to be targeted for sampling while avoiding the zones of transported Regolith.
- Detailed petrographic studies including ore petrography of host rocks, alteration zones, and mineralized sections are essential for characterizing lithological units and identifying source minerals responsible for anomalous concentrations of critical elements. Such studies play a vital role in delineating enriched mineralized zones. For instance, in zoned LCT-type pegmatites, minerals like tourmaline and apatite tend to occur closer to the quartz core, often in association with beryl, whereas muscovite and biotite are more common

towards the altered wall rock, where Ta-bearing and Li-bearing minerals are frequently encountered. Thus, petrography aids not only in understanding the mineralogy of the deposit but also in guiding exploration by pointing towards favourable alteration halos. Incorporating petrographic analysis into successive stages of exploration, particularly G3 and G2, helps validate geological and geochemical interpretations. Furthermore, it significantly directs beneficiation studies, as detailed mineralogical knowledge is critical for selecting and optimizing appropriate processing techniques.

- Initial sampling methods including rock chip, stream sediment, channel, or trench samples are essential to preliminarily evaluate mineral potential.
- Sampling strategies should be determined by the nature and orientation of the ore body. Linear or structurally controlled mineral bodies require systematic channel or trench sampling at regular intervals along profiles laid at a regular spacing. The spacing of successive channels/trenches can be designed as per the commodity being targeted. However, a standard channel/trench spacing of 200m is recommended.
- Conversely, for non-trending bodies of irregular shape or non-linear mineralized bodies, such as granitoids and alkaline complexes, necessitate grid-based sampling patterns to effectively characterize the dimension of the mineralization. A grid spacing of 200X200m is recommended.
- For targeting Regolith hosted critical minerals in lateritic and bauxitic covers, orientation survey along the exposed profiles or sampling through shallow auger drilling is to be done to establish the secondary enrichment of critical mineral and identification of zone that yields anomalous zones of enrichment. Establishing the size fraction for secondary enrichment is crucial as for ion adsorbed type REE would tend to associate with finer clay fractions while the Ni-V silicates/oxide/carbonates tend to be associated with relatively coarser fractions.
- For targeting stratified sedimentary deposits like phosphorite in limestone and glauconite in sandstone-shale-limestone, integration of chemostratigraphy with facies analysis can be crucial during the G4 stage of exploration. Chemostratigraphy helps identify geochemically enriched intervals using elemental markers such as P_2O_5 and K_2O, while facies analysis aids in recognizing shallow marine depositional settings favorable for such mineralization. This combined approach enhances the delineation of potential mineralized zones by correlating geochemical anomalies with specific sedimentary environments formed through primary sedimentation, organic productivity, and diagenetic processes.
- In soil covered areas, systematic sampling of soils, stream sediments, or vegetation to detect anomalies in elemental concentrations that could indicate underlying mineralization. In REE exploration, soil geochemistry in regolith-covered terrains have successfully highlighted areas of monazite concentration through elevated levels of cerium and lanthanum.
- After sampling and acquiring the geochemical analytical results, the dimension and disposition of the mineralised zones need to be established and clearly delineated on the Large-Scale Map (LSM). In case of Regolith hosted mineral targets, vertical zonation of the Regolith profiles leading to secondary enrichment also need to be established.
- After establishing the dimension of the mineralised zone, necessary geophysical surveys can be employed to understand the subsurface continuity of the zone and possible strike

extension in soil covered areas. Non-invasive techniques such as magnetic, radiometric, gravity, induced polarization (IP), and electromagnetic (EM) surveys can be employed to detect subsurface structures, alteration zones, or ore bodies. Gravity surveys are particularly useful in identifying ultramafic bodies that may host Ni-Cu-PGE mineralization.

- Geochemical proxies and pathfinder elements are critical tools in G4 stage exploration. These tools aid to effectively vector and delineate potential mineralized zones over large areas by serving as indirect indicators of the presence of target commodities by reflecting characteristic elemental associations, alteration haloes, and mobility patterns during mineralizing processes. For instance, in lithium exploration within pegmatitic domains, pathfinder elements such as Rb, Cs, Sn, and Ta are commonly used, as they co-enrich with lithium in evolved granitic pegmatites and provide early geochemical signatures. Presence of minerals such as Spessartine Garnet (Mn-Garnet) can also be used as proxy for presence of spodumene/lepidolite, two of the major Li-bearing minerals.
- Isotopic studies serve as powerful tools in G4 stage exploration by providing geochemical fingerprints that help assess the fertility of source rocks and vector toward mineralized zones. Isotope ratios, such as those of sulphur ($\delta^{34}S$), lead (Pb), strontium (Sr), and neodymium (Nd), can reveal the origin, evolution, and fluid sources of mineralizing systems, thereby narrowing down target areas with higher exploration potential. Sulphur isotopes, in particular, are effective in distinguishing between magmatic, sedimentary, and hydrothermal sulphur sources, which is crucial for sulphide-hosted critical mineral deposits. For example, in the exploration of cobalt-bearing sulphide deposits, sulphur isotopic studies MAY be used to differentiate mineralizing events and confirm the presence of hydrothermal fluids with $\delta^{34}S$ values indicative of metal-bearing sources, thereby aiding in vectoring toward high-grade zones.
- Mineral species yielding the anomalous concentration of critical elements are also to be identified through XRD, EPMA, SEM, LA-Q-ICPMS or other methodologies. For graphite, Laser Raman Spectroscopy is a pre-requisite to differentiate between organic/inorganic carbon and graphite as such identification will have significant bearing on resource estimation.
- In the G-4 stage of critical mineral exploration, scout drilling can play a pivotal role in initial subsurface evaluation. This involves widely spaced, shallow boreholes designed to quickly test geophysical or geochemical anomalies identified from earlier surveys. The primary objective is to confirm the presence of target mineralization at depth, understand initial geological controls, and collect preliminary data to guide more detailed G-3 stage exploration.

3. 3 Phase III

Drilling, Core Sampling, Resource Estimation, and Beneficiation Studies (G3 and G2 stage Exploration)

After delineating the mineralised zone for critical mineral and establishing its dimension, it is necessary to establish its lateral persistency and depth continuity which eventually involves drilling. Subsequently, integration of the drilling, geological and geochemical data is to be done to estimate the resource as per established classification scheme.

A) Integration and Acquisition of Data

- All the geological, geochemical and geophysical datasets are integrated with geological mapping and satellite data to generate multi-parameter exploration models to guide the drilling in G3 and G2 stage.
- During the G-3 stage of exploration, detailed geological mapping (DM) is carried out to refine the understanding of lithological, structural, and mineralisation controls within the delineated mineralised zone. This involves high-resolution field mapping at a scale of 1:1,000 to 1:5,000, depending on the geological complexity and size of the target area. Usually, Differential GPS (DGPS) are employed for accurate geospatial referencing, while drone-based photogrammetry and Ortho-mosaic generation enhance topographic accuracy and aid in identifying surface expressions of mineralisation, structural discontinuities, and alteration patterns. The integration of these technologies ensures precise spatial control and can facilitate 3D modelling and supports the planning of subsequent drilling and surface sampling.
- Surface sampling during the G-3 stage is a crucial activity aimed at validating the surface continuity and geochemical signature of the delineated mineralised zones. This involves systematic collection of samples such as chip, channel, or trench samples across the mapped lithological contacts, mineralised bodies. Sample length of channels and trenches can be kept at 0.5 to 1m, depending on the targeted critical mineral, ore body type and surface exposure, with precise geolocation recorded using GPS. All samples are subjected to standardized preparation and analysis protocols to ensure reproducibility and data integrity. The results are integrated with geological mapping to guide subsurface exploration and refine drilling targets.
- As critical minerals often occur in specific geological settings, detailed geophysical survey of suitable technique help in identifying subtle signatures that may be overlooked in broader surveys. Thus, prospect level geophysical surveys are to be conducted prior to drilling, especially in areas with thick soil/alluvium covers. For example, graphite and associated Vanadium exploration in graphite-rich schists of Arunachal Pradesh leverages high-resolution geochemical signatures and electrical conductivity anomalies to map mineral-rich horizons.
- Subsequently, Geophysical derivative maps and inversion models are to be prepared as these are indispensable tools for targeting critical minerals and effectively guiding drilling campaigns. Derivative maps, such as total magnetic intensity (TMI) derivatives (e.g., first vertical derivative, analytic signal), enhance subtle anomalies and delineate geological structures, faults, and contacts that often control mineral deposition, helping to locate prospective zones from raw airborne or ground geophysical data. Building on this, geophysical inversion models transform measured geophysical responses into 3D subsurface distributions of physical properties (like density, susceptibility, or conductivity), providing a more realistic and quantitative image of concealed ore bodies or alteration zones. This 3D understanding significantly reduces exploration risk by identifying the precise location, depth, and geometry of potential critical mineral targets, thereby optimizing drill hole placement and minimizing unnecessary drilling.

B) Drilling

The primary aim of the drilling program is to delineate the size, grade, continuity, and structure of the mineral deposit with a focus on critical minerals. Hence, this pivotal juncture must be regarded as the definitive litmus test of the geological hypothesis meticulously constructed during the antecedent stages of exploration, where the empirical validation either justifies or disproves the conceptual framework developed so far.

- Drilling is carried out for obtaining continuous core samples for lithological, mineralised zones, structural details, and geotechnical analysis.
- It is to be ensured that all the profiles of the proposed boreholes are substantiated with systematic surface sampling (channel/trench) data to aid establishing sub-surface continuity of the surficial manifestation of mineralisation and subsequent resource estimation.
- Drilling parameters such as borehole spacing, depth, and orientation are critical and should be tailored based on the geology and type of mineralization. Initial drilling at G-3 stage can have wider spacing of 200m, which is gradually reduced to 50–100m or closer at G-2 level, during infill drilling stages to upgrade the confidence level of the resource classification. For shallow dipping bedded and stratiform deposits such as phosphorite, Glauconite bearing sediments, bauxites/regolith with critical elements, vertical drilling in G-3 level is preferred. If such deposits are observed to be considerably inclined due to deformation, then inclined drilling may be carried out. As observed in the case of crystalline limestones in Tamil Nadu, a staggered drilling approach may be adopted when the bed thickness is significantly high, necessitating increased drilling meterage to adequately cover the entire thickness of the mineralized zone. The grid spacing, depth of vertical intersection of mineralised zones, number of boreholes in case of bedded and stratiform deposits and other drilling parameters must conform to the specifications outlined in the Mineral Evidence and Mineral Content (MEMC) Rules, 2015, 2021, and any subsequent amendments in future. These parameters should be meticulously planned in accordance with the prescribed typology of the ore body, whether stratabound, vein-type, disseminated, or layered, as defined under the MEMC framework, ensuring geological consistency and compliance at every stage of exploration.
- The drill grid should be designed in a way that captures the structural complexity, mineralization trends, and dip/plunge of the ore body. For non-trending bodies of uneven shape like regolith, carbonatite plugs, granites grid based vertical drilling is preferable. Conversely, for trending and inclined bodies such as pegmatites, deformed layered complexes, Titaniferous-Vanadiferous-Magnetite bands, deformed meta-sedimentary units etc. inclined drilling is preferable.
- Geostatistical studies and 3D geological modelling from previous phases, especially from G-3 stage can be done to help optimize drilling design in G-2 stage and reduce uncertainty in resource estimation.

C) Geological Borehole Logging

Geological logging of boreholes during the G-3 and G-2 stages is essential for constructing a detailed lithostratigraphic framework and understanding the vertical and lateral continuity of mineralised zones. Core logging involves the systematic documentation of lithology, mineral assemblages, texture, structure, alteration patterns, and visible mineralisation. In the G-3 stage, emphasis is placed on correlating surface geology with subsurface observations, while in the G-2 stage, detailed logging supports geostatistical modelling and resource estimation. All observations are recorded using standardized logging templates, and core recovery, RQD, and structural measurements are also documented to assess core quality and structural controls on mineralisation.

D) Geophysical Borehole Logging

Geophysical logging in boreholes complements geological logging by providing in-situ continuous measurements of physical properties such as resistivity, natural gamma radiation, density, magnetic susceptibility, and conductivity. In the G-3 stage, borehole geophysics helps identify mineralised zones, delineate lithological contacts, and detect alteration halos that may not be visually apparent. At the G-2 stage, apart from the previous, advanced downhole tools such as spectral gamma-ray, borehole imaging (televiewer), and electromagnetic sondes can be utilized to enhance the resolution of subsurface data. These logs are crucial for refining ore body geometry, aiding 3D modelling, and improving the accuracy of resource classification.

E) Borehole Core Sampling

- Typically, core samples are selected based on visual mineralisation. Usually, sampling at 1.0 m intervals is done for REEs, while for critical minerals like Mo, or W, sampling intervals of 0.5–1.0 m are followed depending on style of mineralisation. Half of the cores after carrying out sample procedure are to be preserved for future reference.
- Before sending core samples to chemical laboratories, a preliminary assessment for trace and critical element enrichment can be conducted using rapid, in-situ tools like handheld X-ray fluorescence (XRF) and Laser-Induced Breakdown Spectroscopy (LIBS). These portable devices provide quick, semi-quantitative elemental analysis and help guide targeted sampling, particularly useful for detecting critical elements such as lithium, REEs, and transition metals. However, results must be interpreted cautiously and calibrated against standards.
- The selected core samples are processed by drying, pulverising to the required mesh size, followed by thorough homogenisation using the coning and quartering method, and approximately 250 grams of the prepared sample is then dispatched for chemical analysis.

F) Sampling of non-mineralised zones

Among the drilled boreholes, one borehole should be specifically selected for sampling of non-mineralised zones. Preference should be given to the borehole that intersects the maximum number of lithological units/zonal variation present within the exploration block, thereby providing the representative cross-section of the local geology. This approach ensures comprehensive geochemical characterization of various rock types and enables better detection of critical mineral which may not be visible through visual inspection. The sampling strategy should be tailored according to the thickness and nature of the lithological/zonal variations identified as non-mineralised with respect to the primary commodity targeted in the exploration program. A complete chemical analysis of major oxides and trace elements covering all the critical elements are to be carried out for the representative stratigraphic borehole. While selecting the critical elements for analysis, the geological set-up and lithological variants are to be considered. For example, mafic-ultramafic rocks may be analysed for their Ni-Cu-Cr-Co content while acidic/alkaline rocks such as granitoids are to be analysed for REEs and Rare Metals (RMs).

However, in certain special scenarios, the sampling of non-mineralised zone may be restricted to particular lithounit(s)/zone(s) that has/have mineralisation potentiality in accordance with established geological concepts. For example, the PGE analysis may be restricted to core samples comprising mafic to ultramafic lithologies intersected in the borehole. Similarly, Fixed Carbon analysis for graphite needs to be done using Raman Spectroscopy for graphite mineralization within the core, ensuring analytical relevance and cost-effectiveness.

The following strategy may be adopted towards sampling for critical minerals and trace elements:

- Chip samples, representative of length of the core, are to be pulverized and homogenized. Representative samples from such pulverized and homogenized rocks are to be collected by applying the method of coning and quartering.
- If the lithology thickness is greater than 10 m, then sampling to be done at an interval of 5 m.
- If the lithology thickness is 5-10 m, then two samples to be collected at equal interval.
- If the lithology thickness is 1-5 m, then one sample may be collected.
- If the lithology thickness is between less than 1 m, then one sample may be collected.

G) List of primary commodity and associated elements/commodities

Primary Commodity (Major Mined Metal/Ore)	**Expected Associated / Secondary Commodities**
Copper (Cu)	Molybdenum (Mo), Rhenium (Re), Gold (Au), Silver (Ag), Selenium (Se), Tellurium (Te), Uranium (U), Rare Earth Elements (REE), Indium (In), Germanium (Ge), Cobalt (Co)
Iron (Fe)	Vanadium (V), Titanium (Ti), Phosphorus (P), REEs (especially in BIFs and laterites), Niobium (Nb), Zirconium (Zr)
Lead (Pb)	Silver (Ag), Zinc (Zn), Cadmium (Cd), Antimony (Sb), Indium (In), Bismuth (Bi)
Zinc (Zn)	Lead (Pb), Silver (Ag), Cadmium (Cd), Germanium (Ge), Indium (In), Gallium (Ga)
Gold (Au)	Silver (Ag), Copper (Cu), Tellurium (Te), Bismuth (Bi), Arsenic (As), Antimony (Sb), Platinum Group Elements (PGEs), Mercury (Hg)
Nickel (Ni)	Cobalt (Co), Copper (Cu), Platinum Group Elements (PGEs), Scandium (Sc), Chromium (Cr)
Chromium (Cr)	Nickel (Ni), Cobalt (Co), Platinum Group Elements (PGEs), Vanadium (V)

Primary Commodity (Major Mined Metal/Ore)	Expected Associated / Secondary Commodities
Bauxite (Aluminium Ore)	Gallium (Ga), Vanadium (V), Scandium (Sc), REEs (in lateritic profiles), Titanium (Ti), Zirconium (Zr)
Phosphate (P)	Rare Earth Elements (REEs), Uranium (U), Fluorine (F), Strontium (Sr), Vanadium (V), Scandium (Sc)
Uranium (U)	Vanadium (V), Molybdenum (Mo), Selenium (Se), REEs, Rhenium (Re), Copper (Cu), Scandium (Sc)
Tin (Sn)	Tungsten (W), Tantalum (Ta), Niobium (Nb), Indium (In), Lithium (Li), REEs, Zirconium (Zr)
Tungsten (W)	Tin (Sn), Molybdenum (Mo), Bismuth (Bi), Tantalum (Ta), Niobium (Nb), REEs
Platinum Group Metals (PGEs)	Nickel (Ni), Copper (Cu), Gold (Au), Silver (Ag), Cobalt (Co), Chromium (Cr), Selenium (Se), Tellurium (Te)
Manganese (Mn)	Cobalt (Co), Nickel (Ni), Lithium (Li), REEs
Lithium (Li)	Cesium (Cs), Rubidium (Rb), Beryllium (Be), Tantalum (Ta), Tin (Sn), Boron (B)
Graphite	Vanadium (V), REEs, Lithium (Li), Nickel (Ni) (in associated rocks or tailings)
Rare Earth Elements (REEs)	Scandium (Sc), Thorium (Th), Uranium (U), Zirconium (Zr), Niobium (Nb)
Tantalum (Ta)	Niobium (Nb), Tin (Sn), Lithium (Li), REEs
Cobalt (Co)	Copper (Cu), Nickel (Ni), Manganese (Mn), PGEs
Molybdenum (Mo)	Rhenium (Re), Copper (Cu), Tungsten (W), Selenium (Se)

H) Resource Estimation

Once sufficient drill data and chemical analytical result is available, resource estimation is to be carried out following internationally accepted codes such as the United Nations Framework Classification (UNFC) to ensure transparency, uniformity, and investor confidence in reporting mineral resources. An appropriate resource estimation methodology shall be employed based on the geometry, style of mineralisation, and spatial disposition of the ore body, whether stratabound, vein-type, disseminated, or layered. Geostatistical techniques such as Inverse Distance Weighting (IDW), Ordinary Krigging, or simulation methods may be adopted, as deemed suitable. The exploration report must include a comparative analysis of resource estimates derived from the applied methodologies, highlighting the variability, confidence levels, and reliability of each approach to support classification under the UNFC framework.

The estimated resources are usually categorized into different classes such as 334, 333 or 332 for G4, G3 and G2 stages respectively, which reflect the levels of geological confidence and economic feasibility. Critical minerals need to be prioritized in the estimation process due to their strategic importance, and the estimates may be regularly refined using 3D modelling and geostatistical tools. The classification helps determine the readiness of the project to transition into pre-feasibility or feasibility studies and guides further decisions.

I) Beneficiation Studies

Beneficiation study is a key component of Phase III, as it provides insights into the processing behaviour of the ore and helps identify the most suitable extraction techniques. Laboratory-scale tests such as flotation, magnetic separation, gravity separation, and leaching, are conducted on representative core samples to evaluate mineral liberation characteristics, recovery rates, and concentrate quality.

- For instance, lithium-bearing pegmatites may require flotation to separate spodumene, while nickel-cobalt laterites may be processed using hydrometallurgical methods like high-pressure acid leaching (HPAL). The outcome of these tests directly influences plant design, process flow sheets, and preliminary economic assessments.

4. Methods of analysis of different elements including critical and trace elements

Different analytical techniques are employed based on the type, concentration, and matrix of elements to be analysed, especially in the context of critical and trace element exploration. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is widely used for detecting ultra-trace concentrations of elements such as REEs, Li, Be, Sc, etc. and precious metals, owing to its high sensitivity and precision. X-Ray Fluorescence (XRF) is commonly used for major and minor oxides such as Fe_2O_3, Al_2O_3, SiO_2, TiO_2, and elements like Cr, Mn, Zr, and Nb in solid matrices. Atomic Absorption Spectroscopy (AAS) is used for selective analysis of metals like Pb, Cd, and As, often in environmental or metallurgical contexts. Fusion and wet chemical methods are employed for total analysis of refractory minerals or when digestion is required for complete breakdown. A proper selection of analytical technique is essential for accurate characterization of ores and host rocks in mineral exploration. Each step must be performed with strict quality control to ensure the integrity and representativeness of the analytical results. A generalised guideline for adopting suitable analytical procedure is provided in the table below:

A. Recommendations of analytical techniques/methodologies/ protocols for chemical analysis of rock samples

Analytical Methods		Elements with LLD values	Alternate Method	Remarks
WD-X-Ray Fluorescence Spectrometry (WD-XRF)	Pressed-Pellet for Major Oxides, Minor Oxides & Trace Elements	Major Oxides, Minor Oxides & Trace Elements: SiO_2 (0.1%), Al_2O_3 (0.1%), Fe_2O_3 (0.1%), MnO (0.01%), MgO (0.1%), CaO (0.1%), Na_2O (0.1%), K_2O (0.1%), TiO_2 (0.01%), P_2O_5 (0.01%), Ba (50 ppm), Cu (10 ppm), Pb (10 ppm), Zn (10 ppm), Ni (10 ppm), Co (10 ppm), Cr (15 ppm), Ga (5 ppm), Rb (5 ppm), Sc (5 ppm), Sr (5 ppm), V (20 ppm), Y (5 ppm), Zr (5 ppm), Nb (5 ppm), Th (4 ppm)	1. Base Metals by Acid digestion followed by AAS: Cu (10 ppm), Pb (10 ppm), Zn (10 ppm), Ni (10 ppm), Co (10 ppm), Cr (15 ppm). 2. Alkali fusion method followed by ICPMS: Y (5 ppm), Zr (5 ppm), Nb (5 ppm), Th (4ppm)	Fusion Bead for Major Oxides may be adopted considering the nature of sample
Inductively Coupled Plasma Mass Spectrometry (ICPMS)	Fusion Method	REE & Trace Elements: La (1 ppm), Ce (2 ppm), Pr (0.1 ppm), Nd (0.3 ppm), Sm (0.1 ppm), Eu (0.02 ppm), Gd (0.05 ppm), Tb (0.03 ppm), Dy (0.03 ppm), Ho (0.01 ppm), Er (0.02 ppm), Tm (0.02 ppm), Yb (0.02 ppm), Lu (0.02 ppm); Be (0.3 ppm), Ge (0.05 ppm), Sn (5 ppm), Hf (0.5 ppm), Ta (0.2 ppm), Th (4 ppm), U (0.5 ppm), Y (5 ppm), Zr (5 ppm), Nb (5 ppm), Rb (5 ppm), Mo (0.5 ppm), W (0.5 ppm)	1. By XRF: Y (5 ppm), Zr (5 ppm), Nb (5 ppm), Th (4ppm), Rb (5 ppm) 2. Acid digestion method followed by ICPMS: Mo (0.5 ppm), W (0.5 ppm)	
	Acid-Digestion Method	Trace Elements: Li (5 ppm), Mo (0.5 ppm), In (0.03 ppm), Te (0.05 ppm), Sb (0.2 ppm), Cs (2 ppm), W (0.5 ppm), Tl (0.05 ppm), Bi (0.2 ppm)	1. Mo (0.5 ppm), W (0.5 ppm) by ICPMS Fusion Method 2. Li (5 ppm), Cs (2 ppm) by Acid digestion followed by AAS 3. Sb (0.2 ppm) Bi (0.2 ppm) by Acid digestion followed by HG-AAS	
AAS	MIBK Extraction	Au (50 ppb)		
Lead Fire Assay	AAS/ICP-MS	Au (50 ppb), Pt (5 ppb), Pd (5 ppb)		

Analytical Methods		Elements with LLD values	Alternate Method
Hydride Generation AAS	Acid Digestion	As (2 ppm), Se (0.2 ppm), Sb (0.2 ppm), Bi (0.2 ppm)	1. As (2 ppm) by ICPMS Fusion Method 2. Sb (0.2 ppm) Bi (0.2 ppm) by Acid digestion followed by ICPMS
Flame-AAS/ICP-OES	Acid Digestion	Base Metals: Cu (10 ppm), Pb (10 ppm), Zn (10 ppm), Ni (10 ppm), Co (10 ppm), Cr (15ppm)	Cu (10 ppm), Pb (10 ppm), Zn (10 ppm), Ni (10 ppm), Co (10 ppm), Cr(15ppm) by XRF
	Acid Digestion	Ag (2 ppm), Cd (5 ppm)	
Ion Selective Electrode (ISE)	Fusion	F (100 ppm)	
Direct Mercury Analyser (DMA)	Direct	Hg (5 ppb)	
Fire Assay – Nickel & Inductively Coupled Plasma Mass Spectrometry	FA-Ni & ICPMS	PGE: Pt (5 ppb), Pd (5 ppb), Rh (3 ppb), Ir (3 ppb), Ru (3 ppb)	
Coal/Graphite Analysis	Proximate Analysis by TGA/Classical	Moisture, Volatile matter, Ash, Calorific Value, Fixed carbon, Bulk Density	
Halite Analysis (Flame Photometer, UV-VIS Spectrophotom eter, Classical Method)	Water leaching	Na (0.01%), K (0.01%), Ca (0.01%), Mg (0.01%), Cl (1.00%) and SO_4 (0.1%),	ICP-OES Na(0.01%), K(0.01%), Ca(0.01%), Mg(0.01%)
Reactive Silica, FeO, S	Wet Classical Method	Reactive Silica (0.1%), FeO (0.1%), S (0.1%)	S (0.1%) by XRF
Gas Analysis (H_2, He, N_2, CO, CO_2, C_1-C_4, Ar)	Marine Sediment & Geo-Thermal Projects (Gas Chromatography)	H_2, He, N_2, CO, CO_2, C_1-C_4, Ar (ppm to %)	
TOC Analyzer	Direct	TC (Total Carbon), TIC (Total Inorganic Carbon), TOC (Total Organic Carbon) (5ppb)	

B. Chemical analysis of water samples

Analytical Methods (As per BIS/APHA methods)		Elements/Radicals / Analytes
Wet Classical and Instrumental	pH, Conductivity and TDS Meter, UV-Vis Spectro- photometer, ISE-meter, Flame Photometer, ICP-OES, AAS	pH, TDS, Conductivity, Total Hardness, CO_3^{2-}, HCO_3^-, Cl^-, F^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, SiO_2, B
Inductively Coupled Plasma Mass Spectrometry (ICPMS)	Acid treatment	Trace Elements
Direct Mercury Analyser (DMA)	Direct	Hg

5. Conclusion:

The results of Exploration of Non-Coal and associated rocks for exploration of Critical and Strategic Minerals should be systematically presented in a detailed report. These reports should be prepared following completion of each phase or stage of work. At the conclusion of Phase III, the Geological Reporting Requirement is to be accomplished as per the reporting template of the GSI. However, the resource estimation should abide by the internationally accepted UNFC codes and following MEMC protocol. The geological report must detail the exploration activities and findings thereof.

Appendix II

STANDARD OPERATIONAL PROCEDURE (SOP) FOR SAMPLING AND ANALYSIS OF COAL AND ASSOCIATED ROCKS FOR EXPLORATION OF CRITICAL AND STRATEGIC MINERALS

BACKGROUND

Ministry of Coal, vide its OM (55027/3/2007-CRC-1(Vol-II) dated 10th April 2023, proposed for explorations of other minerals during the course of coal exploration under CSS scheme. In this connection, Ministry of Mines was requested to provide some inputs on the detailed process of exploration of other minerals as followed by GSI. In response to the request, GSI was asked whether there has been any attempt to explore other minerals associated with coal and its associated rocks while doing coal explorations and if it was in a position to prepare an SOP for exploration of the other minerals. Replying to the query, GSI mentioned that no systematic sampling has ever been carried out by GSI for other minerals. However, a list of few exploration programmes was prepared where coal and its associated rocks were randomly sampled and tested for REE and other trace elements. In some rare instances where sedimentary rocks occurring above the coal zones in some of the coalfields were found to contain REE in high concentration were also listed. It was also mentioned in the reply that since the concentration of REE and other trace elements in coal can increase manyfold following ashification, fly ash can be economically exploited for REE. GSI agreed to the proposal of preparing an SOP for the exploration of other minerals during the course of coal exploration and accordingly kept an agenda in the 19th CGPB, Committee V meeting held on 12th September 2023. In the meeting, it was decided that a SOP in this regard would be formulated and shared with the Committee V members who are directly involved in the exploration and exploitation of coal.

CONTENTS

1. PURPOSE

The use of coal as the major source of power is to be gradually phased out[#] because of its detrimental effect on the environment. Instead, coal may be used to exploit elements that are associated with coal in traces. For example, apart from its primary ore deposit within sulfides, economic deposits of Germanium (Ge) are known to be associated with coal also. China has established that both REE and Li can be economically exploited from coal.

2. SCOPE

The modes of occurrence of elements in coal are a consequence of the various processes occurring during peat deposition and subsequent geological processes during diagenesis and epigenesis.

Mode of occurrence and concentration of trace elements and REEs vary greatly in coal seams as follows:

(i) Enrichment only in roof and floor rocks, not in coals.

(ii) Enrichment not only in roof and floor rocks but also in coals.

(iii) Enrichment in thin partings of shale/clay within coal.

This SOP deals with the techniques of identifying the possible zones of REE and Trace element concentration in a sedimentary column with or without coal or lignite. It is applicable to all Indian Gondwana and Tertiary coal and lignite fields as well as any other sedimentary basins.

The concentration of trace elements in coal shall increase 5-7 times when coal is burned to ash. This shall not happen for traces occurring in dirt bands/partings. Keeping the above possibilities in mind, a data inventory is to be prepared where coalfield-wise, the trace element distribution will be recorded for all the correlatable planes. Coalfield-wise analysis of the data would help in identifying the prospective areas.

3. IDENTIFICATION OF THE ZONES ENRICHED IN REE AND TRACE ELEMENTS (GE AND LI)

REEs, mainly LREEs are concentrated in accessory minerals (bastnaesite, monazite, xenotime *) or clay minerals (kaolinite, illite) in coal and as heavy minerals in the associated siltstone or fine-grained sandstone. It is reported that in REE-enriched coal, REEs mostly occur in both authigenic grains of REE bearing minerals, and in adsorbed forms on the organic matter or clay minerals. Although REEs in coal are mainly found associated with minerals, HREEs generally have a greater organic affinity and are preferentially complexed with the organic components than LREEs.

Lithium (Li) is mainly enriched in authigenic minerals like kaolinite and chlorite along with some organic components, while Ge exclusively displays an organic affinity and a clearly preferential enrichment in organic fractions.

3.1 Identification of REE bearing mineral enriched coal and associated rocks in borehole core

In addition to the coal zones, REE can also occur in layers occurring in sediments overlying or underlying the coal zones. In sediments, it can occur within its host mineral like monazite, bastnasite,

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#Ministry of New and Renewable Energy posted an article titled “Government’s approach for reducing use of fossil fuels and to promote production of renewable energy from bioenergy sources, including from agricultural residue” on 07 DEC 2023 8:41PM by PIB Delhi

*Three principal sources of REE (RARE EARTHS Indian Minerals Yearbook 2019 – IBM) xenotime or as ion adsorbed on clay minerals. The host minerals due to the presence of U or Th are radioactive and have high sp. gravity. It is therefore possible that these radioactive minerals get concentrated in siltstone or fine-grained sandstone layers of the Gondwana sediments. REE-bearing minerals can also occur in coal beds. Apparently, the natural gamma ray log can be a useful tool for identifying REE-rich horizons in coal as well as in the associated sediments.

Monazite, a reddish-brown phosphate mineral, contains rare-earth elements and is often associated with thorium and uranium. Monazite is radioactive due to the presence of thorium and, less commonly, uranium. Similarly, both bastnaesite and xenotime are also radioactive and thorium bearing. Monazite is the most common REE bearing mineral among the three.

It is possible to identify monazite-rich zones (or bastnaesite/ xenotime rich zone or all possible combinations of the three) in borehole cores using the spectral gamma logs. The spectral-gamma log measures the natural gamma radiation emitted by the rocks in the borehole and can be used to estimate the concentration of naturally occurring radioactive elements such as uranium, thorium, and potassium. Therefore, the presence of monazite (or other radioactive mineral containing thorium) in borehole cores can be detected by analyzing the spectral-gamma log data. All such zones should be clearly indicated in the descriptive and the graphic litholog of the boreholes prepared in a suitable scale. The process is to be followed in all boreholes drilled in an exploration item. In areas of detailed exploration 2/3 boreholes per sq. km may be selected for sampling.

3.2 Coal seams/ zones intersected in borehole core where REE and Ge may occur in ion-adsorbed state

In addition to sampling the REE-enriched zones identified through the gamma-ray log, the method of sampling described below should be followed for all coal zones where REE and Ge may occur in an ion-adsorbed state.

Normally, REE enrichment is reported from the roof or floor rock immediately overlying or underlying a coal seam. If the boundary between coal seam and its roof/floor rock is gradational then there can be enrichment of REE at the top or bottom of the seam also. Accordingly, the following sampling plan has been formulated for coal seams/ zones.

3.2.1. Single coal seams:

(i) **Coal seam thickness of 1m (no parting):** two samples are to be collected from the top and bottom of the seam. More samples may be collected from the roof/floor rocks, close to its contact with the coal seam.

(ii) **Coal seam thickness of more than 1m (no parting):**

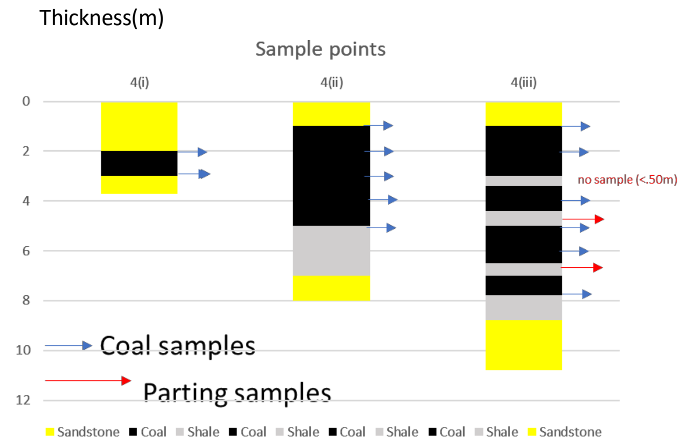
(a) One sample from the top and one from the bottom; and

(b) for the zone between top and bottom, one sample at every 1m interval, starting from top. Since HREE and Ge have greater organic affinity, samples should be collected from within the thick seams.

(iii) **Coal seam thickness of 1m or more (with parting):**

(a) As in (ii);
and

(b) one sample from every parting of more than 0.5m thickness. If any sample point of the one metre interval layout falls on a parting, that sample should not be collected as a coal sample.



Thickness(m)

	(i)	(ii)	(iii)
Sandstone	2	1	1
Coal	1	1	1.9
Shale	0	0	0.4
Coal	0	1	1
Shale	0	0	0.6
Coal	0	1	1.5
Shale	0	0	0.5
Coal	0	1	0.8
Shale	0	2	1
Sandstone	0.7	1	2

3.2.2. Coal seam zones:

a. For a coal seam zone having several coal split sections, for individual splits of thickness 1m and ≥ 1m, samples are to be collected as given in 3.2.1 (i) & (ii).

b. Special care is to be taken while collecting samples from coal seams interlayered with carbonaceous shale/clay beds. For individual layers, samples are to be collected as given in 3.2.1 (iii).

Sampling of partings less than 0.5m thick and coal seams less than 1m thick are avoided because they are normally not correlatable. However, if such partings or coal seams are correlatable with other borehole sections they can also be sampled as described above.

3.3 Identification of Li-rich zones in borehole cores

As mentioned before, Li is normally associated with the clay beds. Therefore, any clay bed that has not been identified for REE or Ge enrichment may be considered for Li enrichment.

3.4. Mine face/ Profile sections

1. For sampling from mine faces/ profiles, a freshly exposed face is to be selected for sampling. Locations showing obvious signs of oxidation, such as red-brown stains or weathering effects are to be avoided. A profile is to be selected having a plane that is normal to the bedding. In general, the locations for sampling in mine faces/profiles should be equally spaced according to the approachability and accessibility of the coal seam in mine faces.

2. A detailed lithological profile with a description of the selected section is to be prepared according to a suitable scale.

3. Section 3.2 should be followed to locate sample points in coal seams/ zones. Apart from coal clay (or kaolinite) beds should be selected for sampling. All fine-grained sandstone or siltstone layers above or below the coal seams, the roof and floor rocks lying immediately above or below a coal seam and the partings of appropriate thickness should be identified for sampling.

4. In case sampling at regular interval is not possible from the mine faces or the mining area covers both mined and unmined areas, boreholes may be drilled afresh at 2-3km spacing and covering all the seams/ seam zones. In situations where sampling is done from both mine faces and from borehole cores a regular spacing is to be maintained between the different sample locations.

4.SAMPLING

a. Coal exploration blocks may be considered as comprehensive units for mineral exploration, requiring investigations not only for augmenting coal resources but also for trace elements, rare earth elements (REE), and other minerals, occurring both, in the sub-surface coal and non-coal zones, and on the surface as well.

b. In the case of borehole cores chip samples are to be collected for REE, Ge and Li from all the corresponding enriched zones identified by following the procedure described above. The collected samples are to be kept in polyethylene-lined air-tight canvas bags with proper marking of sample number/ID. Check samples are also to be collected. All collected samples are to be later pulverized and homogenized as per the specifications of the chemical laboratory where they are to be submitted for analysis in ICPMS.

c. Handheld X-ray Fluorescence (XRF) instruments can also be used for the rapid detection of REE and Trace elements in the selected samples. Handheld XRF analyzers are portable and non-destructive instruments that can provide rapid geochemical analysis of geological samples in the field. Handheld XRF may also be useful to locate if any ion-adsorbed REE-enriched zones are present in coal. However, it is important to note that handheld XRF instruments are semi-quantitative and the results should be interpreted with caution. The accuracy of XRF measurements can be influenced by factors such as the matrix effects of the sample, the presence of other minerals in the sample, and the calibration of the XRF instrument. Therefore, it is recommended to use handheld XRF instruments in conjunction with other analytical techniques such as scanning electron microscopy (SEM) or X-ray diffraction (XRD) or Inductively Coupled Plasma Mass Spectrometry (ICPMS) to confirm the presence of REE bearing minerals and to find their actual concentration.

d. The non-mineralized portion, i.e., stratigraphic horizons without coal, of at least 1 no. borehole in a coal exploration block may be entirely sampled. Preference should be given to the borehole that intersects the maximum number of lithological units/zonal variation present within the exploration block, thereby providing the representative cross-section of the local geology. This approach ensures comprehensive geochemical characterization of various rock types and enables better detection of critical mineral which may not be visible through visual inspection. The sampling strategy should be tailored according to the thickness and nature of the lithological/zonal variations identified as non-mineralised with respect to the primary commodity targeted in the exploration program. These lithounits are to be entirely sampled, based on the thickness of the unit. Chip samples, representative of length of the core, are to be pulverized and homogenized. Representative samples from such pulverized and homogenized rocks are to be collected by applying the method of coning and quartering.

The following strategy may be adopted towards sampling for critical minerals and trace elements:

- If the lithology thickness is greater than 10m, then sampling to be done at an interval of 5m.
- If the lithology thickness is 5-10m, then two samples to be collected at equal interval.
- If the lithology thickness is 1-5m, then one sample may be collected.
- If the lithology thickness is between 0.5-1m, then one sample may be collected.
- If the lithology thickness is less than 0.5m, then sampling of such units may be avoided.

The depth zones should be carefully recorded in all such samples. Whole rock analysis (major oxide) may also be carried out in borehole samples for classification of rocks and to decipher provenance, tectonic setting and weathering history.

5. ANALYSIS OF THE SPATIAL VARIATION IN CONCENTRATION OF REE AND OTHER TRACE ELEMENTS

In case of explorations carried out in G3, G2 or G1 stage, where boreholes are drilled in a standard grid, the concentrations of the REE and Trace elements obtained at different borehole locations in a given correlatable plane are to be analyzed for their spatial variation using standard gridding techniques (e.g. krigging, linear etc.). The same method should be followed for all the correlatable planes. Zones with suitable concentration can be taken for a higher stage of exploration or mining.

6. PROPER ESTIMATION OF THE ELEMENTAL CONCENTRATION AND THEIR MODE OF OCCURRENCE

Analysis of trace elements and REE can be best done through Inductively Coupled Plasma Mass Spectrometry (ICPMS). The most important part of the analysis is the Standard Reference Materials (SRM) used for the standardization of the analysis. There should be use of internationally accepted SRM as standards for coal and associated carbon-rich sediments so that the analyses would be more precise, accurate and acceptable to the geoscientific community.

Understanding the nature of the occurrence of trace elements and REE in mineral sites and/or with organic compounds in coal and their microstructural characterization is of prime importance for the feasibility of their extraction. The following analytical techniques may be adopted to find the mode of occurrence of REE and other trace elements in coal and associated rocks.

i) **X-ray diffraction (XRD):**

As the accuracy of XRF measurements can be influenced by several factors, it is recommended to use handheld XRF instruments along with XRD to understand the mineralogical association contributing to the bulk inorganic geochemistry of the sample. Identification of the REE-bearing minerals through XRD analysis in coal/shale samples is essential, particularly from the zone of interest, if evidenced by XRF analysis.

ii) **Scanning electron microscopy (SEM)**

SEM analysis is required for high-resolution images for the identification of micron-sized REE-bearing phases, which occur within the pore spaces of organic material or as adsorbed phases on the surface of clay minerals.

iii) **Inductively Coupled Plasma Mass Spectrometry (ICPMS)**

ICPMS is used to measure the concentrations of rare earth elements (REE) in shale, coal, and associated sediments. The general concentration of REE and trace elements in ppm level can be quantitatively and accurately determined through ICPMS. Critical trace elements like Li having a highly volatile nature and very low atomic weight can be effectively detected and quantified by ICPMS. The most important part of the analysis is the certified Standard Reference Materials (SRM) used for the standardization of the analysis. Internationally accepted SRM / CRM like NIST SRM 1632b and 1633b may be used as standards for coal and associated carbon-rich sediments. NIST is the National Institute of Standards and Technology at the U.S. Department of Commerce.

7. RECOMMENDATION

The sampling techniques laid out in the SOP are to be used in different blocks in different coalfields to assess the efficacy of the laid out techniques and the results obtained from these studies can be used for updating and fine tuning the SOP which in turn would help In wide spread adoption of the SOP by all organizations engaged in coal explorations.

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Appendix III

Standard Operating Procedure (SOP) for Assessment of Critical Minerals in exploration of Minor Minerals and their mine dumps

1. Introduction

In India, minor minerals are defined as those that are not classified as major minerals by the Government of India. They primarily include building stones, gravels, ordinary clay, ordinary sand (other than sand used for prescribed purposes), dolomite, granite, and other locally occurring materials of similar nature. These minerals are generally utilized for local construction and allied purposes and are not typically used in major industrial applications. Large numbers of minor mineral mines, both operative and closed, are distributed across the country, notably in Rajasthan, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Telangana, Tamil Nadu, Kerala, Odisha, Karnataka, and Jharkhand.

Assessment of the critical mineral potentiality of minor mineral blocks proposed for auction is essential to ensure comprehensive resource evaluation and informed decision-making. Several lithological types hosting minor minerals, such as laterite, bauxite, dolomite, and kaolin, are known to contain trace but significant concentrations of critical or strategic elements like scandium, gallium, germanium, and rare earth elements. For instance, lateritic and bauxitic horizons in parts of Odisha and Chhattisgarh have shown enrichment in scandium and gallium, which are vital for high-technology and green energy applications. Evaluating such potential before auction allows the State Government or the proposing agency to recognize and document the broader resource value of the block, ensure transparent valuation, and prevent inadvertent loss of critical minerals through conventional mining operations. Incorporating this assessment as a pre-auction requirement strengthens sustainable mineral management and aligns with the national objective of securing indigenous sources of critical minerals.

Besides the above, mining and processing of minor minerals also generate substantial quantities of waste materials in the form of overburden, waste rock, subgrade material, tailings, and process residues. For instance, calcination of minerals such as china clay, bentonite, or dolomite can yield residues like slag and tailings, while processing of minerals such as corundum or granite produces dumps composed of host rock fragments and associated gangue materials. These wastes, which are often stored in designated dump yards or dry stacks within the leasehold area, may contain silicates, oxides, and other mineral phases that can host trace quantities of valuable or critical elements.

Furthermore, natural weathering and alteration processes acting over time may lead to geochemical modifications and localized enrichment of certain critical or strategic elements in such mine wastes, especially in lateritic, kaolinitic, or clay-rich environments. These transformations enhance the potential of mine dumps, tailings, and other residues to serve as secondary sources for future resource recovery.

To address these challenges, a standardized evaluation framework aligned with global best practices is essential. This includes adopting modern sampling strategies, and robust analytical techniques to assess the critical mineral potentiality of the mine faces and mining residues such as dumps, tailings from existing or closed minor mineral mines. As part of this approach, exploration of minor mineral deposits should also incorporate evaluation for the presence of critical minerals, given their growing strategic importance. Such efforts can not only support sustainable resource recovery from legacy minor mineral mines but also systematic assessment of critical mineral potential of minor mineral blocks prior to auctioning.

2. Objectives

The objective of this SOP is to:

- Establish critical mineral potential, if any, of minor mineral blocks prior to auctioning
- Establish a standardized and reproducible methodology for assessing critical or other mineral potential in mine dumps of minor minerals.
- Identify and quantify economically viable concentrations of critical or other elements using systematic surface sampling.
- Integrate geochemical and mineralogical data to understand the potential.

3. Pre-Auction sampling for minor mineral blocks

To ensure that mineral potential, including the presence of associated critical or strategic elements, is adequately assessed prior to allocation, the following provision shall be applicable:

- Prior to the proposal of any block of minor minerals for auction, the proposing agency, whether the State Government or any other authorized entity, shall mandatorily ensure the collection and analysis from each proposed block as per the guidelines given below.
    - The proposing agency shall conduct a geological appraisal of the block using available geological, geochemical, and remote-sensing data, followed by field verification to identify lithological variations and potential sampling sites.
    - A minimum of five (05) sampling points shall be selected to ensure coverage of all lithological units or facies present within the block. For blocks exceeding 10 hectares or showing significant lithological variation, the number of samples may be increased proportionally to maintain representative coverage, generally at an interval of 200–300 meters depending on outcrop conditions.
    - In homogeneous deposits such as river sand or gravel, samples shall be collected along a transect covering upstream, midstream, and downstream segments of the proposed block. In case of lateritic, dolomitic, or kaolinitic deposits, samples shall be drawn from surface exposures, shallow pits, or active faces to capture in-situ material composition.
    - Fresh surface samples shall be collected from exposed sections/faces and outcrops. Where surface exposure is limited, pitting or trenching up to suitable depth (generally 1–2 m) shall be undertaken to obtain fresh, unweathered material. In deposits with deeper mineralization or concealed lithology, limited drilling may be carried out to recover representative subsurface samples, if required.
    - Each sample (approximately 5 kg) shall be free from contamination, properly labelled, geo-tagged, and documented with photographs. The samples shall be

dried, crushed, and pulverized to suitable size fraction for geochemical analysis using nationally accredited laboratories equipped with analytical techniques such as XRF/ICP-MS/AAS or other suitable instruments for determining critical element concentrations.

- The analytical results, along with detailed information on sampling locations, methodologies adopted, and interpretations, shall be compiled in a brief report and submitted to the auctioning authority prior to auction.
- This provision shall be uniformly applicable to all categories of minor mineral blocks proposed for auction to ensure that the potential for recovery of associated critical or strategic minerals is duly assessed and documented. In blocks where significant concentrations of critical commodities are established, such blocks may be earmarked for detailed exploration to assess their potential for critical minerals.

4. Sampling Methodology for Existing Minor Mineral Mines (closed or ongoing)

Sampling in existing minor mineral mines, whether operational or closed, is essential to evaluate the potential for recovery of associated critical or strategic minerals from mine faces, waste dumps, tailings, subgrade material, and process residues. Such mines may contain unnoticed or unassessed mineralized fractions due to the earlier focus on extraction of only the principal minor mineral. The following section describes the methods to carry sampling of different components generated during the mining activity.

A. Pre-Sampling

- Pre-sampling considerations should include a historical review of document on ore types, available geochemical analysis, beneficiation techniques and deposition sequences. This would provide a firsthand information on what associated commodity is expected along with the minor mineral that was/is being mined. Such data is essential for formulating an effective assessment methodology for historic mine dumps.
- Another crucial step is to identify the different stratum/layers within the dump as prolonged degradation of dump materials often leads to elemental differentiation in different layers viz. REEs tend to be concentrated in finer fractions. Moreover, it also leads to development of spatial heterogeneity that necessitates rigorous grid sampling.

B. Surface Sampling

Surface sampling is crucial for any mineral assessment program. Surface sampling of waste dumps, mineral reject/subgrade dumps, mineral stacks, screen reject dumps etc. can be a complex process. Each type of the dump has its unique challenge. Thus, sampling methodology will vary based on the nature and type of dump.

a) In mine dumps, material size ranges from fine particles to large boulders, and the quality varies due to mixed waste from different lithounits. These dumps are typically extensive in height and spread, with significant lateral and vertical variability developed over time, making representative sampling challenging. To obtain preliminary information, four surface samples can be collected from each dump by digging pits of 0.5 m × 0.5 m × 0.5 m after clearing the surface for vegetation and other contaminants. Excavated material should be placed on a clean tarpaulin, boulders broken down as needed, and reduced to ~5 kg using coning and quartering. In each dump four such types of pits may be dug at suitable locations. The pits are to be divided in four quadrants and one sample may be drawn from each quadrant. The samples generated shall be kept in separate sample bags.

b) For mineral stacks and mineral reject dumps which normally has a uniform size of material, and the quality of the material is more or less same, grab sampling is to be done. Grab samples are to be collected in a suitable grid interval of say 150m*150m. The samples drawn may then be crushed to less than 25mm size. If the grab samples from a grid node are heterogeneous in nature in terms of size, shape, quality or other characters, composite sampling should be carried out by homogenising the different types of materials present at that grid node. However, if the material is uniform in shape, size, and quality, a single representative sample of up to 5 kg may be collected from each grid node at the preliminary stage. Sampling should also be done for other categories of dumps such as screen rejects, subgrade dumps etc.

C. Surface sampling in grid Pattern

Dumps which show promising results of possibilities of critical minerals based on the study as per Part B above, may be covered under systematic surface sampling. Surface geological sampling in a grid pattern is a systematic method used to ensure uniform and representative coverage of an area for mineral assessment.

- The grid can be designed by dividing the target dump site into evenly spaced intervals with sample points laid along rows and columns. The grid spacing can typically range from 50x50 meters to 100x100 meters depending on deposit type, heterogeneity and size of the dumps. However, for smaller size dumps grid spacing closer than 50m may be done.
- Samples are to be collected at each grid point/node, i.e. at the intersection points of the rows and columns of the grid to capture spatial variations in elemental concentrations.
- Once the spatial dimension of the anomalous zone with elevated concentration of the targeted elements is determined, close space surface sampling in grid interval of 25X25m or closer (depending upon the dimension of the dump) may be carried out to increase resolution of the analytical data.
- If the top part of the dump has well-developed vegetation, pitting of appropriate volume at each sample location point on the grid is to be done to collect less altered samples that would closely resemble the unweathered dump materials.
- Adequate amount of samples is to be collected, weighing at least 5 kgs. The sample locations are to be geo-tagged, and photographs capturing each location along with the sampling methodology should be documented for future reference.

5. Other Sampling

Accurate assessment of associated critical mineral potentiality relies heavily on systematic sampling across all operational stages of the mine. The following sections detail the structured methodologies for collecting representative samples from mine faces, beneficiation and processing plants or dumps, and slags, thus underpinning a sound assessment framework.

The sample locations are to be geo-tagged, and photographs capturing each location along with the sampling methodology should be documented for future reference.

A. Sampling of mine faces

Sampling of mine faces involves systematic collection of samples separately from each litho-unit (rock formation) exposed in the mine benches by cutting channels. For this purpose, a suitable mine section may be selected across the entire mine pit which exposes all or the maximum number of lithounits including the mineralized zone available in a mine. Once the profile is selected, then a channel outline of 5 to 10 cm width may be drawn across the general strike of the minor mineral bearing zone and other rock formations. Then channel incision up to a depth of approximately 10 cm is to be made and channel samples are to be collected while keeping the sample length of up to 1m. Samples are to be collected at regular interval.

In case of underground mines, sampling is to be done in developed stopes, both from the hanging wall and footwall sides. Sampling of both ore and wastes may be done separately. Extreme Care is to be taken to ensure that there is no contamination between the samples collected from different litho-units.

B. Sampling from beneficiation and processing plants

In case of beneficiation and processing plants existing within the lease then approximately 2kg of samples shall be drawn from each stage of processing such as feed stage (after crushing but before any screening), screen rejects, middling's from each stage and then samples of the final products and process remains.

C. Sampling of slags generated from the smelting plants

For sampling of slag dumps the same procedure may be adopted as described at 3B.(a) above.

D. Drilling

If drilling is involved in the assessment of critical mineral potential of mine dumps of minor minerals, the methodology outlined in Section 3D of the *'Standard Operating Procedure (SOP) for Assessment of Critical Minerals in Mine Dumps and Tailings (Non-Coal)'* should be referred and followed.

6. Sample Processing and preservation

Rock samples intended for geochemical analysis should undergo meticulous preparation to ensure homogeneity and accuracy.

- The process typically begins with air drying or oven drying of collected rock samples to remove moisture.
- Once dried, samples are to be crushed to reduce them to smaller fragments. These fragments are to be pulverized using suitable sample processing instruments to achieve a fine, homogeneous powder, generally to a particle size of <75 microns (200 mesh).
- To minimize contamination, the crushing and pulverizing equipment must be cleaned thoroughly between samples.

- The powdered sample are to be subjected to coning and quartering to obtain a representative sub-sample for geochemical analysis.
- At least 50% of each powdered samples are to be preserved for future reference.
- All samples are to be stored in 20-micron poly bags and then put in cloth bags and securely tagged and numbered. The samples generated from sulphide ores (viz. copper, lead and zinc mines) should be stored in airtight zip pack polybag to avoid oxidation and contamination of the samples.
- Each step must be performed with strict quality control to ensure the integrity and representativeness of the analytical results.

7. Data Interpretation and Potentiality assessment

Data interpretation and potentiality assessment of critical minerals associated with minor minerals involve a systematic evaluation of geochemical, mineralogical, and spatial data derived from sampling, beneficiation studies. Since mining operations for minor minerals do not target critical elements directly, their occurrence is often incidental or in trace amounts. Therefore, interpreting data requires identifying geochemical anomalies, elemental associations, and enrichment trends within mine waste, dumps, or host rocks like laterite, shale, mica schist, or clay bands.

To assess such potentiality, Handheld XRF and LIBS instruments can be utilised to readily determine the chemical concentrations of elements in mine dump materials. These techniques are rapid and non-destructive. XRF provides quick elemental analysis, especially for metals like V, Cu, Zn, and REEs, while LIBS offers high-resolution detection of light elements such as Li, Be, and B, often missed by XRF. Together, they enable on-site screening, guiding targeted sampling and reducing laboratory dependency, thereby accelerating the evaluation of dump materials for resource potential.

Integration of lithological context, elemental concentrations and their spatial distribution helps delineate zones with higher concentrations of critical elements such as REEs, Ga, Sc, etc. These insights form the basis for assessing the economic potential, prioritizing targets zones, and evaluating the feasibility of secondary resource recovery from dumps.

8. Expected associated commodities along with primary commodity

The extraction of minor minerals through mining can potentially yield associated elements that can hold significant strategic value, especially in the context of rising global demand for critical minerals. These associated commodities may occur as trace constituents or by-products within the minor-mineral bearing lithology which can be recovered during processing or retained in mine waste, or smelter residues. The following table provides a comprehensive overview of the typical associated commodities expected alongside minor minerals, with particular emphasis on critical elements. As a practice, along with assessing the mine dumps, exploration for minor minerals should also focus on analysing these elements to assess associated mineral potentiality. If drilling is conducted during the exploration of minor minerals such as laterite, gypsum, or dolomite, the sampling and analysis of associated elements should be carried out in accordance with the methodology outlined in Sections 3.3B, 3.3E, and 3.3F of the *'Standard Operating Procedure (SOP) for Exploration of Non-Coal Minerals'*.

Minor Mineral	Possible Associated Critical and Other Minerals
1. Agate	Fe, Mn
2. Ball Clay/China Clay/Clay (Others)/Kaolin	REEs, Ga, V, Sc, Ti, Ni (especially in lateritic environment)
3. Calcareous Sand	Sr, REEs (trace)
4. Calcite/Chalk	Sr, Mn, Ba
5. Corundum	Cr-Ni-Ti-Fe-V (in associated with ultramafic rocks, Be (in pegmatitic settings)
6. Diaspore	Ga, Sc (in bauxitic profiles)
7. Dolomite	Mg, Mn, Sr, REEs when associated with carbonatites
8. Dunite/Pyroxenite	Cr, Ni, PGE, Co, V, REEs when associated with intrusive
9. Felsite	Li, Be, Sn, W, REEs (in felsic intrusive)
10. Fuschite Quartzite	Cr, V (trace)
11. Gypsum	P, F, Sr, REEs and Se (in association with phophogypsum)
12. Jasper	Fe, Mn, sometimes Au in BIF-related settings
13. Laterite	Ni, Co, Sc, REEs, Ga, Al, V, Ti
14. Limekankar	Sr
15. Ochre	Fe, Mn
16. Pyrophyllite	REEs (trace)
17. Quartzite	Fe, Mn (trace)
18. Sand (Others)/silica sand	Ti, Zr, REEs, Th, U (esp. in beach or heavy mineral sands), high purity silica sand
19. Shale	V, Li, Co, Ni, Mo, REE
20. Slate	V, Li, Co, Ni, Mo, REE
21. Steatite (Talc)	Ni, Cr, Co (in ultramafic settings)

Appendix IV

Standard Operating Procedure for Assessment and Evaluation of Critical and Strategic Elements associated with Atomic Minerals Deposits explored by Atomic Minerals Directorate for Exploration and Research (AMD) and Mines under the purview of AMCR, 2016

1. Background:

The Atomic Minerals Directorate (AMD), a constituent unit of the Department of Atomic Energy (DAE), Government of India, is mandated to carry out exploration in diverse geological domains, including hard rock and placer environments, for the identification and evaluation of mineral resources containing uranium (U), thorium (Th), niobium (Nb), tantalum (Ta), beryllium (Be), lithium (Li), zirconium (Zr), titanium (Ti), rare earth elements (REE) associated with uranium and thorium, and other critical elements of relevance to the programmes of the DAE. Besides, AMD approves the mining plan and perform role of Regulatory Authority in respect of *atomic minerals* [listed under Part B, First Schedule of the Mines and Minerals (Development and Regulation) Act, 1957 i.e. MMDR Act, 1957] equal to or above the threshold value as specified in Schedule A of AMCR, 2016 notified by Government of India from time to time.

Recently, Government of India has announced National Critical Mineral Mission (NCMM), 2025 to develop a resilient critical mineral supply chain in India and fast-tracking of critical minerals value chains, sustainable mining and leveraging technology for decarbonisation. AMD has already taken proactive initiatives towards the NCMM in terms of assessment and evaluation of critical minerals associated commonly within the ore zone of *atomic minerals* deposit(s) in India.

2. Existing SOP of AMD for Associated Critical Minerals in the Ore Zones of Atomic Minerals:

Over the last seven and half decades, AMD has developed expertise and enhanced its exploration capabilities in exploration and resource augmentation of atomic mineral(s) both in hard rock terrains as well as beach and inland placers of India. The well-established Standard Operating Procedure (SOP) for assessment of associated critical elements within the ore zone of atomic minerals practiced in vogue during course of exploration is as follows:

2.1 In major prospective areas, representative borehole core samples from uranium, REE, pegmatite-hosted lithium, and beach or inland placer deposits are chemically analysed to quantify both principal and associated elements. For uranium ore zones, analyses cover commonly associated elements such as Pb, Zn, Cu, Cd, As, Sb, Bi, Co, Ni, P, Mo and REE, with additional elements including Ga, V, Se, Au, Ag, Cs, Li, Te, Re, Sn, W and PGE examined selectively based on geological context. For REE deposits, associated elements including U, Th, Nb, Ta, Mg, Sr, Ba, V and Sc in carbonatite systems, and U, Th, Nb, Ta and Zr in alkaline granite or rhyolite tuff systems, are analysed. In pegmatite (LCT)-type lithium deposits, REE and associated elements such as U, Th, Nb, Ta, Ce and Be are routinely assessed. For beach and inland placers, the quantification of monazite and zircon, along with ilmenite, rutile, leucoxene, garnet and sillimanite, is carried out to determine their resource potential.

2.2 Resources of the associated critical elements available in the delineated ore zones of the *atomic minerals* are duly estimated and reflected in the Geological Reports (GR) of the deposits submitted by AMD to respective State Government(s) to initiate the process of grant of mining lease as per the provisions of Rules 4(5)(b) of AMCR, 2016.

2.3 As special assignments during the year 2020, mill tailings of M/s Uranium Corporation of India Limited (UCIL) uranium mines located in Jharkhand (Jaduguda: old and new tailing pond and Turamdih tailing pond) and Andhra Pradesh (Tummalapalle tailing pond) have been sampled (preliminary) and chemically analysed for Cu, Mo, Co, Ni, V and REE. Besides, feasibility studies have also been carried out by M/s UCIL through IIT-ISM, Dhanbad for recovery of uranium from copper tailings of M/s Hindustan Copper Limited (HCL) at Mosabani Plant. The report indicates that the copper tailings contain about 90ppm of U_3O_8 with a recovery of 62%.

2.4 However, it may be noted that the systematic sampling of tailing ponds is constrained by waterlogged marsh / swampy conditions leading to inaccessibility to the central part of the ponds. Consequently, the generated samples do not represent the entire tailing column, and as a result, although the assessment of the available critical elements could be fairly done through chemical analysis of the samples generated, the actual evaluation of available resource remains a challenge.

3. Extended SOP for Sampling of Associated Critical Minerals in Ore Zones of Atomic Minerals:

Government of India is framing various policies to meet the growing demands for critical minerals towards achieving "Net Zero" carbon emission by the year 2070. In order to develop an uninterrupted critical mineral(s) supply chain to cater to the need for technology towards decarbonisation, it is desirable to formulate the guidelines by respective stake holders to assess the occurrence of associated critical minerals in the primary ore zones at different stages of exploration leading to establishment of the upcoming deposit(s) as well as existing mines that are already under operation. AMD, being an exploration agency as well as the Regulatory Authority in respect of *atomic minerals*, proposes the following guidelines for assessment and evaluation of associated elements at different stages of exploration as well as in existing operational mines under the ambit of mineral laws in vogue.

3.1. Sampling and Assessment during Exploration Stage

Exploration activities for AMD are fairly spread across diverse geological domains (hard rocks and placers) covering different exploration stages from Reconnaissance Survey (G4), Preliminary Exploration (G3), General Exploration (G2) and Detailed Exploration (G1) through surface and sub-surface exploration techniques. In view of the above, sampling for assessment of associated critical elements in the ore zones may be taken up at different stages of exploration **without losing focus on *primary atomic minerals*** being explored.

a. During ground surveys and prospecting (Regional / Semi-detailed surveys), representative samples may be drawn from exposures of major lithounits and in-situ soils in the area and mineralising zone of *atomic minerals* in particular to assess the occurrence of associated critical elements based on geological favourability for hosting these elements.

b. During sub-surface exploration, representative samples may be drawn from overburden, barren, mineralised and alteration zones to assess the occurrence of associated critical elements based on geological favorability of hosting these elements.
    i. Representative sample (borehole composite) from overburden and barren zone may be restricted to major correlatable lithounits intercepted in boreholes and collected at 1 km x 1 km grid or one (01) borehole per sq km.
    ii. Representative samples from atomic mineral(s) ore zones may be collected as per exploration norms in vogue to access the associated critical elements in the respective ore zones.
    iii. Representative samples from megascopically identifiable alteration zones, sulphide zones and unconformity contacts may be collected as per exploration norms in vogue to access the potentiality of probable critical elements associated in these zones based on geological understanding.
    iv. Representative samples (surface and subsurface) may be drawn from beach and inland placers to access the potentiality of valuable minerals other than the beach sand minerals based on geological understanding.

c. The samples collected / generated during the course of surface and subsurface exploration as mentioned in (b) above may be analysed as per the details below.

Deposit Type	Elements to be Analysed	Remarks
Uranium Deposits	Pb, Zn, Cu, Cd, As, Sb, Bi, Co, Ni, P, Mo, **REE**	Additional elements (Ga, V, Se, Au, Ag, Cs, Li, Te, Re, Sn, W, PGE) may be analysed based on geological evidence
REE Deposits – Carbonatite	U, Th, Nb, Ta, Mg, Sr, Ba, V, Sc	REE to be treated as a group (La–Lu + Y)
REE Deposits – Alkaline Granite / Rhyolite	U, Th, Nb, Ta, Zr	—
LCT-Pegmatite Lithium Deposits	Li, U, Th, Nb, Ta, Cs, Ce, Be, **REE,** Sn	Te, Re, We, Se and W also be analysed based on geological evidence
Beach and Inland Placer Deposits	Monazite (Th+REE), Zircon (Zr), Ilmenite, Rutile, Leucoxene, Garnet, Sillimanite	Additional minerals (xenotime, cassiterite, gold, PGE) may be analysed based on geological evidence

Provided that in case of other important associated minerals / elements like xenotime, cassiterite, gold and PGE, the samples may be judiciously analysed, in certain cases, based on the geological understanding (set up) and their possible association.

d. Geological Report(s) submitted by the Directorate to respective State Government(s) shall invariably incorporate the resources of the associated critical elements available in the delineated ore zones of the *atomic minerals* to initiate the process of grant of mining lease as per the provisions of Rules 4(5)(b) of AMCR, 2016 in respect of *atomic* and associated critical minerals.

Provided that in case of evidence of associated critical elements, if any, in the megascopically identifiable alteration / sulphide zones or along unconformity contacts may suitably be incorporated in the geological report.

3.2. Sampling and Assessment for Existing Operational Mines

The Director, AMD is notified as the Competent Authority to approve the mining plans and perform the functions of a regulatory authority in respect of atomic minerals (equal to or above threshold value) under provisions of AMCR, 2016 and the Mineral Conservation and Development Rules (MCDR), 2017. At present, the Directorate is regulating the operational mines of uranium and BSM in different parts of the country as per the approved mining plans of AMD. The association of critical elements in the operational BSM mines has been fairly established. However, the study on associated critical elements in the existing uranium mines operated over several decades is very limited and scanty. In order to assess and evaluate critical elements / minerals associated in existing and upcoming uranium mines, the Regulatory Authority may direct the mining lease holder(s) to carry out / facilitate sampling and analysis under the ambit of extant mineral laws in vogue.

a. During course of exploratory mining and subsequent mining operations, systematic samples may be drawn from overburden, barren zones, ore zone, stacked subgrade ores and tailing ponds by implementing best suitable method of sampling to assess the occurrence of associated critical elements based on geological favorability of hosting these elements.
    i. Representative composite samples may be generated from overburden and barren zone during the course of exploratory mining/shaft sinking/extension of shaft sinking restricted to major litho-units.
    ii. Representative samples shall be generated from the ore zone during the course of exploratory mining.
    iii. Representative samples shall be generated from the development mine faces in the ore zone during the course of mine operation.
    iv. Systematic sampling of tailing ponds representing the entire tailing column and stacked subgrade ores/mine dump shall be carried out at regular intervals (time).
        a. Tailings, sub-grade materials, mineral rejects, and legacy mine residues shall be subjected to periodic assessment to evaluate the potential for recovery of associated critical and strategic elements. Such analysis shall be carried out in the normal course, at least once every six months.
        b. Wherever sampling is hindered due to waterlogging or inaccessibility, alternative methods such as peripheral or grid-based marginal sampling may be adopted. Limitations of such sampling shall be recorded in the report.
    v. Representative samples may be generated from the borehole cores during the course of geo-technical drilling carried out for mine stability and operational planning studies.
b. The samples collected/generated during the course of exploratory mining and subsequent mining operations as mentioned in (a) above may be analysed either at laboratories funded by NMET under capacity building measures on a free-of-cost basis or through adequate budgetary support from NCMM, 2025.
c. The mining lease holder shall submit online a monthly return incorporating the details of samples generated from each mine and their analytical results, if any.

d. The mine lease holder shall maintain the records of sample generation and their analysis in a systematic way for examination by the Authorized Officer(s) of the Central Government.

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Standard Operating Procedure (SOP) for Assessment of Critical Minerals in Mine Dumps and Tailings (Non-Coal)

1. Introduction

Tailings and mine waste are unavoidable byproducts produced during mining operations, regardless of the commodity extracted. These wastes typically include overburden and waste rock, which are materials surrounding or above the ore body that were economically unfeasible to mine at the time, as well as tailings i.e., the finer residues left behind after ore processing. Additionally, slag, produced during smelting and refining processes, further contributes to these wastes. Typically stored in tailings ponds, dry stacks, or scattered across various depths and locations within the leasehold area pertaining to the mine. Interestingly, natural weathering processes and biogeochemical activities within mine wastes can alter the recoverability of critical minerals, influencing both resource availability and the potential for further environmental degradation.

The rising global demand for critical minerals, driven by their essential roles in green technologies, defence, electronics, and renewable energy, underscores the need to reevaluate mine dumps and tailings as significant secondary sources. These waste deposits, previously overlooked due to technological or economic constraints, often contain recoverable amounts of valuable minerals. Studies by USGS demonstrated that germanium concentrations in copper tailings could reach up to 30 ppm, significantly above crustal averages. ICP-MS analysis and systematic sampling were key to this discovery. Geostatistical Studies and geochemical fingerprinting carried out in Witwatersrand, South Africa revealed REEs, Mo, and Th concentrations in gold and uranium tailings. However, accurate global resource estimation for critical or other metals such as Molybdenum, Indium, Selenium, Cadmium, Tellurium, Germanium, Rhenium, Cobalt, Nickel etc. remains challenging, as these metals are typically unreported in conventional mining records, recovered incidentally during smelting or refining processes. Addressing these challenges requires a standardized assessment framework based on global best practices, modern sampling strategies, and rigorous estimation techniques, thereby improving resource management and exploration priorities.

2. Objectives

The objective of this SOP is to:

- Establish a standardized and reproducible methodology for assessing critical or other mineral potential in mine dumps and tailings.
- Identify and quantify economically viable concentrations of critical or other elements using stratified surface sampling and shallow drilling.
- Integrate geochemical, mineralogical, and metallurgical data for informed resource estimation.

- Reassess mineral potentiality of the historic mine dump materials which were considered uneconomic due to non-availability of technology for extraction of low-grade ores, but present metallurgical advancements allow extraction of low-grade ores.

3. Surface Sampling Methodology

A. Pre-Sampling

- Pre-sampling considerations should include a historical review of document on ore types, geochemical analysis, processing techniques, metallurgical records and deposition sequences. This would provide a first-hand information on what associated commodity is expected along with the primary commodity that was/is being mined. Moreover, information on dump materials containing previously uneconomical lean ores, now potentially viable due to advancements in technology or changes in extraction grade, would be crucial. Such data is essential for formulating an effective assessment methodology for historic mine dumps.
- The study of legacy data should be complemented by DGPS or drone surveys to accurately map topography and dump morphology.
- Another crucial step is to identify the different stratum/layers within the dump or tailings as prolonged degradation of dump materials often leads to elemental differentiation in different layers viz. REEs tend to be concentrated in finer fractions. Moreover, it also leads to development of spatial heterogeneity that necessitates rigorous grid and stratified sampling.

B. Surface Sampling

Surface sampling is crucial for any mineral assessment program. Surface sampling of waste dumps, mineral reject/subgrade dumps, mineral stacks, screen reject dumps, tailing dumps/tailing ponds etc. can be a complex process. Each type of the dump has its unique challenge. Thus, sampling methodology will vary based on the nature and type of dump.

(a) In case of waste dump, the size of materials varies widely particularly from fines to boulders as big as 1.5mt in dimension. The nature of the material in terms of quality also varies as all types of mine waste from various lithounits are dumped together. The height and spread of such dumps are also very high. Further as the dumps are created over a period of time, the quality of the material may vary widely from place to place both laterally and vertically. Drawing any representative samples from such dumps may be extremely difficult. However, to have an initial idea about the dump surface samples by digging pits of 0.5m*0.5m*0.5m depth after creating a freshly exposed surface may be done. The excavated material shall be kept over a neat and clean tarpaulin. In case of any boulders are encountered, the size of the same may be reduced suitably. The entire excavated material shall be reduced by systematic coning and quartering to approx. 5kg. In each dump four such types of pits may be dug at suitable locations preferably by dividing the pit in four quadrants and one sample may be drawn from each quadrant. The samples generated shall be kept in separate sample bags.

(b) For mineral stacks and mineral reject dumps which normally has a uniform size of material, and the quality of the material is more or less same, grab sampling is to be done. Grab samples are to be collected in a grid interval of say 150m*150m. The samples drawn may then be crushed to less than 25mm size. If the grab samples from a grid node are heterogeneous in nature in terms of size, shape, quality or other characters, composite sampling should be carried out by homogenising the different types of materials present at that grid node. However, if the material is uniform in shape, size, and quality, a single representative sample of up to 5 kg may be collected from each grid node at the preliminary stage. Sampling should also be done for other categories of dumps such as screen rejects, subgrade dumps, and tailing dumps.

C. Surface sampling in grid Pattern

Dumps which show promising results of possibilities of critical minerals based on the study as per Part B above, may be covered under systematic surface sampling. Surface geological sampling in a grid pattern (Fig. 1) is a systematic method used to ensure uniform and representative coverage of an area for mineral assessment.

- The grid can be designed by dividing the target dump/tailing site into evenly spaced intervals with sample points laid along rows and columns (Fig. 1). The grid spacing can typically range from 50x50 meters to 100x100 meters depending on deposit type, heterogeneity and size of the dumps.
- Samples are to be collected at each grid point/node, i.e. at the intersection points of the rows and columns of the grid to capture spatial variations in elemental concentrations. For example, elements, known to have highly heterogenous distribution in rocks such as Gold, Molybdenum etc., may require initiation of sampling in 50X50m spacing, while for copper, REEs 100X100m grid spacing can be sufficient.
- Once the spatial dimension of the anomalous zone with elevated concentration of the targeted elements is determined, close space surface sampling in grid interval of 25X25m may be carried out to increase resolution of the analytical data and to aid resource estimation with greater confidence.
- If the top part of the dump has well-developed vegetation, pitting of appropriate volume at each sample location point on the grid is to be done to collect less altered samples that would closely resemble the unweathered dump materials.
- Adequate amount of samples is to be collected, weighing at least 5 kgs. The sample locations are to be geo-tagged, and photographs capturing each location along with the sampling methodology should be documented for future reference.

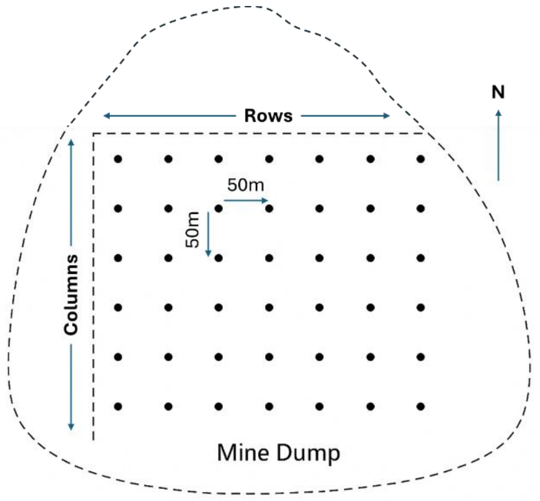

Fig. 1 Schematic diagram showing surface sampling location lay out in grid pattern (assuming grid interval: 50mX50m)

D. Detailed Sampling by Drilling

It may be noted that the mine dump and tailings can be highly heterogenous, possibly more than what the rocks at the mine site portrays. Therefore, vertical drilling to depths up to the basal layer of the mine dump is essential to validate and corroborate the geochemical data obtained from surface. Drilling being a very time consuming and costly affair only those dumps which show promise based on initial surface sampling may be considered for drilling. Drilling will help in getting an idea about the vertical sectional profile of a dump and also help in proper estimation of resources.

- Drilling within mine dumps and tailings requires specialized methods suited to unconsolidated or semi-consolidated material.
- Drill holes should be laid out in a systematic grid pattern, preferably at surface sample location points (Fig. 1).
- To maintain hole integrity in loose or collapsible material, PVC casing should be used throughout the drill hole to prevent collapse and contamination between sample intervals.
- Once drill samples are retrieved, they must be carefully processed to preserve their integrity and extract meaningful data.
- Systematic logging of each sample at regular depth intervals is to be done.
- All the recovered material from drilling should be photographed with scale to create a permanent visual record, aiding in future analysis and verification.
- To support accurate resource estimation, bulk density must be measured for each interval where bulk density is essential for converting volume to tonnage.
- For future reference, sufficient quantity of samples from the entire length of the borehole is to be preserved after collecting the required quantities for geochemical analysis.

4. Other Sampling

Accurate mineral resource estimation relies heavily on systematic sampling across all operational stages of the mine. The following sections detail the structured methodologies for collecting representative samples from mine faces, beneficiation and processing plants, tailing dams or dumps, and slags from smelting plants, thus underpinning a sound assessment framework. The sample locations are to be geo-tagged, and photographs capturing each location along with the sampling methodology should be documented for future reference.

A. Sampling of mine faces

Sampling of mine faces involves systematic collection of samples separately from each litho-unit (rock formation) exposed in the mine benches by cutting channels. For this purpose, a suitable mine section may be selected across the entire mine pit which exposes all or the maximum number of lithounits including the mineralized zone available in a mine. Once the profile is selected, then a channel outline of 5 to 10 cm width may be drawn across the general strike of the ore body and other rock formations. Then channel incision up to a depth of approximately 10 cm is to be made and channel samples are to be collected while keeping the sample length of up to 1m. Samples are to be collected at regular interval.

In case of underground mines, sampling is to be done in developed stopes, both from the hanging wall and footwall sides. Sampling of both ore and wastes may be done separately. Extreme Care is to be taken to ensure that there is no contamination between the samples collected from different litho-units.

B. Sampling from beneficiation and processing plants

In case of beneficiation and processing plants existing within the lease then approximately 2kg of samples shall be drawn from each stage of processing such as feed stage (after crushing but before any screening), screen rejects, middling’s from each stage and then samples of the final products and process tailings.

C. Sample from tailing dams/dumps

After beneficiation and processing of the ROM and the refineries, the tailings are stored in tailing ponds or in tailing dumps. The location of these dumps/ponds may be located inside or outside the lease area. Representative samples from these tailing ponds/dumps are to be collected for analysis. The same procedure as described at 3B.(b) above may be adopted for sampling of tailing ponds and dumps. In case of tailing ponds samples may be collected from few locations all along the periphery of the pond. The samples may then be thoroughly mixed and dried. After drying, the sample size may be reduced to approximately 2.0 kg by coning and quartering. Similarly in case of tailing dumps, samples may be collected from multiple locations of the dump by creating fresh surfaces. The samples may then be thoroughly mixed, and the sample size reduced to 2.0kg by coning and quartering.

Based on the outcome of surface sampling detailed drilling may be taken up as proposed at 3D.

D. Sampling of slags generated from the smelting plants

For sampling of slag dumps the same procedure may be adopted as described at 3B.(a) above.

5. Sample Processing and preservation

Rock samples intended for geochemical analysis should undergo meticulous preparation to ensure homogeneity and accuracy.

- The process typically begins with air drying or oven drying of collected rock samples to remove moisture.
- Once dried, samples are to be crushed to reduce them to smaller fragments. These fragments are to be pulverized using suitable sample processing instruments to achieve a fine, homogeneous powder, generally to a particle size of <75 microns (200 mesh).
- To minimize contamination, the crushing and pulverizing equipment must be cleaned thoroughly between samples.
- The powdered sample are to be subjected to coning and quartering to obtain a representative sub-sample for geochemical analysis.
- At least 50% of each powdered samples are to be preserved for future reference.
- All samples are to be stored in 20-micron poly bags and then put in cloth bags and securely tagged and numbered. The samples generated from sulphide ores (viz. copper, lead and zinc mines) should be stored in airtight zip pack polybag to avoid oxidation and contamination of the samples.
- Each step must be performed with strict quality control to ensure the integrity and representativeness of the analytical results.

6. Data Interpretation and Resource Estimation

Converting analytical and field data into quantifiable resource estimates is a critical step in assessing the economic viability of mine dumps and tailings.

A. Methodologies and Best Practices

- **Volume Determination**: The first step in resource estimation is volume determination of the dump or tailings body. This is most effectively achieved through generating detailed 3D topographic models. These digital elevation models help define the physical extent and stratigraphic layering within the dump, serving as a foundation for volumetric calculations.
- **Grade Estimation:** It is performed by integrating analytical data derived from surface, stratified, and drill samples. These data points can be interpolated using advanced geostatistical methods such as kriging, inverse distance weighting (IDW), or Gaussian simulation, depending on the data density and variability. These techniques help predict the spatial distribution of target elements within the dump at different depth, offering insight into zones of higher concentration.

7. Expected associated commodities along with primary commodity

The extraction of primary commodities through mining often yields a host of secondary or associated elements that can hold significant economic and strategic value, especially in the context of rising global demand for critical minerals. These secondary commodities may occur as trace constituents or by-products within the ore body, often recovered during processing or retained in mine waste, tailings, or smelter residues. The following table provides a comprehensive overview of the typical secondary or associated commodities expected alongside major primary mined metals and ores, with particular emphasis on critical and technology-enabling elements.

Primary Commodity (Major Mined Metal/Ore)	**Expected Associated / Secondary Commodities**
Copper (Cu)	Molybdenum (Mo), Rhenium (Re), Gold (Au), Silver (Ag), Selenium (Se), Tellurium (Te), Uranium (U), Rare Earth Elements (REE), Indium (In), Germanium (Ge), Cobalt (Co)
Iron (Fe)	Vanadium (V), Titanium (Ti), Phosphorus (P), REEs (especially in BIFs and laterites), Niobium (Nb), Zirconium (Zr)
Lead (Pb)	Silver (Ag), Zinc (Zn), Cadmium (Cd), Antimony (Sb), Indium (In), Bismuth (Bi)
Zinc (Zn)	Lead (Pb), Silver (Ag), Cadmium (Cd), Germanium (Ge), Indium (In), Gallium (Ga)
Gold (Au)	Silver (Ag), Copper (Cu), Tellurium (Te), Bismuth (Bi), Arsenic (As), Antimony (Sb), Platinum Group Elements (PGEs), Mercury (Hg)
Nickel (Ni)	Cobalt (Co), Copper (Cu), Platinum Group Elements (PGEs), Scandium (Sc), Chromium (Cr)
Chromium (Cr)	Nickel (Ni), Cobalt (Co), Platinum Group Elements (PGEs), Vanadium (V)
Bauxite (Aluminium Ore)	Gallium (Ga), Vanadium (V), Scandium (Sc), REEs (in lateritic profiles), Titanium (Ti), Zirconium (Zr)
Phosphate (P)	Rare Earth Elements (REEs), Uranium (U), Fluorine (F), Strontium (Sr), Vanadium (V), Scandium (Sc)
Uranium (U)	Vanadium (V), Molybdenum (Mo), Selenium (Se), REEs, Rhenium (Re), Copper (Cu), Scandium (Sc)
Tin (Sn)	Tungsten (W), Tantalum (Ta), Niobium (Nb), Indium (In), Lithium (Li), REEs, Zirconium (Zr)
Tungsten (W)	Tin (Sn), Molybdenum (Mo), Bismuth (Bi), Tantalum

Primary Commodity (Major Mined Metal/Ore)	Expected Associated / Secondary Commodities
	(Ta), Niobium (Nb), REEs
Platinum Group Metals (PGEs)	Nickel (Ni), Copper (Cu), Gold (Au), Silver (Ag), Cobalt (Co), Chromium (Cr), Selenium (Se), Tellurium (Te)
Manganese (Mn)	Cobalt (Co), Nickel (Ni), Lithium (Li), REEs
Lithium (Li)	Cesium (Cs), Rubidium (Rb), Beryllium (Be), Tantalum (Ta), Tin (Sn), Boron (B)
Graphite	Vanadium (V), REEs, Lithium (Li), Nickel (Ni) (in associated rocks or tailings)
Rare Earth Elements (REEs)	Scandium (Sc), Thorium (Th), Uranium (U), Zirconium (Zr), Niobium (Nb)
Tantalum (Ta)	Niobium (Nb), Tin (Sn), Lithium (Li), REEs
Cobalt (Co)	Copper (Cu), Nickel (Ni), Manganese (Mn), PGEs
Molybdenum (Mo)	Rhenium (Re), Copper (Cu), Tungsten (W), Selenium (Se)

Appendix VI

SOP for sampling and analysis of dump and tailing materials from Coal and Lignite mines and Coal Washery rejects for Critical and Strategic minerals

In opencast mining, the soil and rock material (overburden) that lies above the coal/lignite seams is removed and deposited in designated areas, forming overburden (OB) dumps. The process of dump formation occurs in a specific sequence, based on the type and depth of the material removed. Dumps are structured in multiple benches (terraces / decks), typically 30 meters (max) high, to ensure stability.

A. Sampling norm of Critical and Trace elements in mine dump:

1. The Overburden dump of coal and lignite mines is to be considered as a potential deposit.
2. This is to be done in case of abandoned mines and working mines. In case of newly opening mines, sampling to be carried out at the mine face during development stage as per SOP vide, *SOP for Sampling and Analysis of Coal and associated rocks for Exploration of Trace Elements & REE, 2024* to ascertain the concentration of critical and trace elements in different litho-types to avoid the need for future dump analysis.
3. Dumps may be classified according its size (volume and area) and geometry (slope, height and spread) and to be mapped in suitable scale.
4. Dump sampling may be a complex process as the size of materials in the dumps may vary widely particularly in the overburden dumps. Further as the overburden dumps are created over a period of time, the quality of the material may also vary widely from place to place both laterally and vertically. However, to start with the assessment of potentiality of overburden dump material for critical and trace elements concentration, initially baseline data should be generated and the detailed sampling may be carried out in second phase for such dumps, which show potentiality in first phase of assessment.

B. Baseline Data Generation Plan for OB Dumps:

First-hand information may be drawn by digging pits of 0.5m x 0.5m x 0.5m dimensions after creating a freshly exposed surface. The excavated materials shall be kept on a neat and clean tarpaulin. In case of any boulders are encountered in the pits, the size of the boulder shall be reduced suitably and included in the sampled material. The entire excavated material is thoroughly homogenized and stacked into a square based pile with a height of 0.5m. Then the material quantity of the sample shall be reduced by repeated systematic coning and quartering along with size reduction at each stage to a quantity of approximately 5 Kg. of less than 10mm size. From each dump four such pits may be dug at suitable locations preferably in a grid pattern. Otherwise, four quadrants may be drawn and from each quadrant one sample may be collected. The samples generated shall be kept in separate sample bags. These samples may be analysed to find out concentration of critical and trace elements.

C. Sampling Plan for OB Dumps:

1. A 3D gridding system is to be designed covering the top surface, flank/periphery, benches up to the base of the dump. Grid density is to be adapted according to the size of the dump.
2. In grid-wise sampling the grid, size may be fixed as per the size of Overburden dump. For small dumps the sampling may be carried out in 200mX 200m grid and for large size dumps in 500mX 500m grid.
3. From each grid on the top of OB dump, pit samples are to be collected. From the flank/periphery of the dump, systematic channel samples are to be collected at 1 m depth intervals down to base along each 3D grid. The collected channel samples would represent the particular level of the peripheral sections along each 3D grid.
4. Grid-wise sampling: Pit samples are to be collected from the top and benches of the dump. For pit samples, detailed sampling of bulk rocks and soil is to be conducted, for which at least 20 kg of bulk material to be collected in a minimum of 5 suitable locations from each grid. Similarly, for channel samples from the flank/periphery of the dump, at least 5 kg of bulk material to be collected at 1m interval.
5. Separate samples: It is necessary to give specific sample numbers for pit samples from top and benches of the dump and channel samples from the flank/periphery ensuring each sample unit remains separate and not mixed.
6. Each bulk samples to be prepared/reduced to 5kg (pit samples) to 1kg (channel samples) by following the procedures of crushing, coning and quartering.
7. Geotagging: The sample locations must be geotagged and photographs of the sample locations may be documented for future reference.
8. Each sample to be prepared as per the required mesh size according to the analytical procedure to be followed further.

D. Sampling from Coal Washery Rejects and from reject stockpile/dump:

The method for Coal Washery Rejects sampling from its stockpile/dump for the purpose of analysis is based as per procedure stated in IS:436 (Part 1/Sec1) for sampling of coal and is summarized as below:

1. For the purpose of sampling, the quantity of rejects in stockpile/dump shall be divided, into a suitable number of sub-lots approximately equal weight as specified in Table-1 by suitably marking the lines of demarcation on the surface of the lot.

Table-1: Number of sub-lots/gross samples

Weight of the lot (Metric tonne)	Number of sub-lots/ gross samples
Up to 500	2
501-1000	3
1001-2000	4
2001-3000	5
Over 3000	6

2. The surface of each sub-lot shall be levelled and one point for approximately every 250 metric tonnes of material in the sub-lot shall be chosen at random. A gross sample shall then be taken from each of the sub-lots as per the procedure given below:

a. In case the height of the stock pile is not more than 1.5 m, the material shall be collected at every selected point by taking the whole section of coal washery rejects from top to bottom over the area of a circle of 30 cm diameter. For doing so, coal washery rejects from the surface up to a depth of, approximately 50 cm shall be collected at first. The bottom of the hole so formed shall then be covered by a plate and the material lying on the sides shall be removed up to that plate so that when the hole is dug further (to collect further samples), the rejects from the sides may not fill up the hole by falling down. This procedure is repeated till the bottom is reached.

   NOTE -If the quantity of the material collected in the above manner is less than 350 kg then, additional quantity of material shall be collected from other point(s) chosen for the purpose.

b. In case the height of the stock pile is more than 1.5 m, the sample shall be collected at every selected point by taking the material over an area of a circle of 30 cm diameter and up to a depth of 1.5 m. The manner for taking out the sample shall be as described at point no. (a) above.

c. Geotagging: The sample locations must be geotagged and photographs of the sample locations may be documented for future reference.

d. The gross sample shall be crushed to 50 mm, preferably by mechanical means, mixed thoroughly and quartered. Two opposite quarters shall be retained and the rest rejected. The retained material shall be further mixed together, halved and one & half retained. Thus, ultimately one quarter of the original gross sample is retained and the rest rejected. The material so obtained shall be crushed to 12.5 mm by a jaw crusher and then to 3.35 mm by suitable means. The crushed material shall be reduced by coning and quartering till 2 kg of sample is obtained.

Each sample to be prepared as per the required mesh size according to the analytical procedure to be followed further

E. Analysis of the sample:

Recognized standards (SRM/CRM) may be adopted for analytical procedures and recommended ASTM protocol may be followed by ICP-MS/ ICP-OES method for critical and trace element analysis. Specific protocol is to be followed for analysis of lithium and PGEs, while XRF is to be used for analysis of major and minor elements.

Where promising geochemical results are obtained, shallow drilling (auger/reverse circulation (RC) /core drilling) with specified grid intervals may be conducted to delineate vertical continuity and to estimate resource potential.

After identifying the critical/trace elements enriched zone in the overburden dump, these layers are to be mined out using surface miner technology or other available technology. Combustible and non-combustible material are to be separated from the mined out material. After separation, combustible bands are to be used as feed-stock in thermal power plants from which the fly ash samples are to be analysed for elevated critical/trace mineral enrichment. For non-combustible bands, critical elements to be extracted using suitable technology.

If pyritic specks, bands, or layers are found in overburden materials which are often associated with coal/lignite seams, are to be analysed separately using suitable analytical techniques, since these are potential for Germanium concentrations.

Fig. 1. Mine OB dump with benches

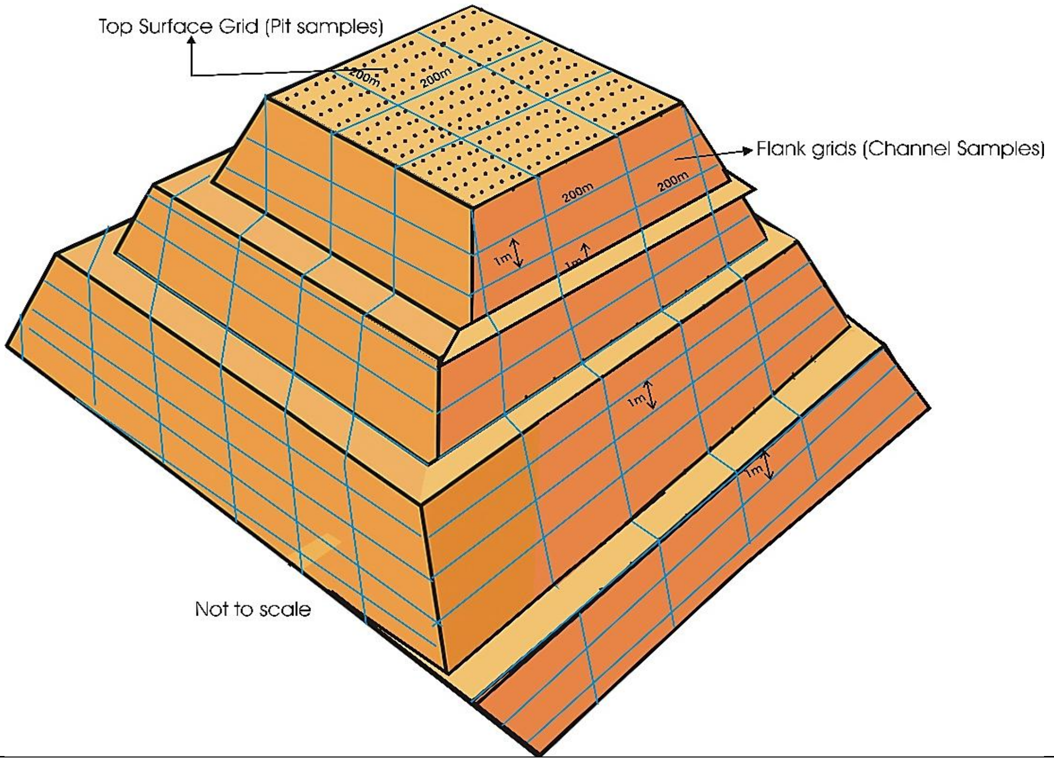

Fig. 2. Graphical representation of 3D grid sampling layout in Overburden dump.