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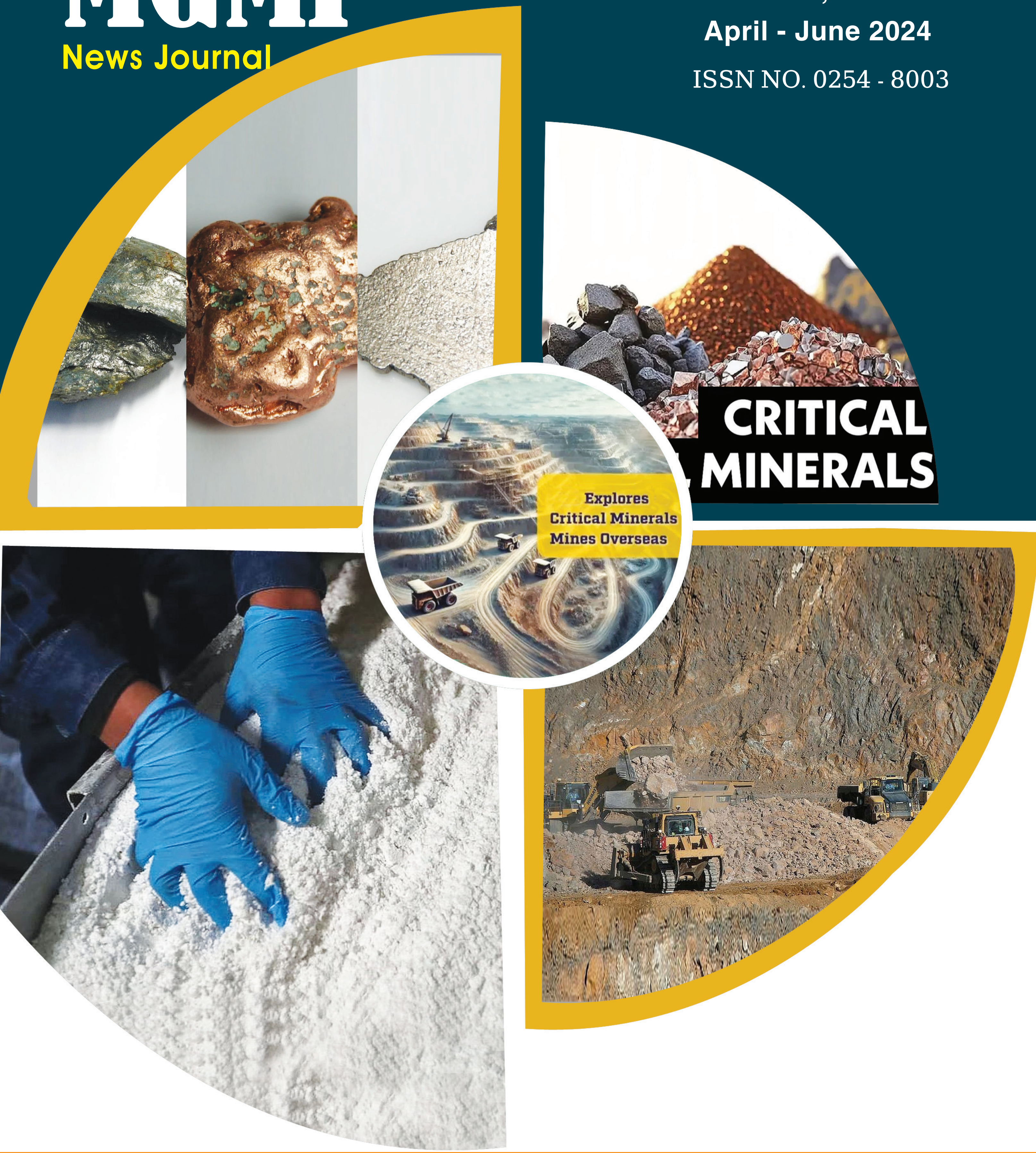

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MGMI NEWS JOURNAL

Vol. 50, No. 1 ● April - June ● 2024

THEME

"Exploring India's Critical Mineral Wealth : Prospects and Challenges"

THE MINING GEOLOGICAL & METALLURGICAL INSTITUTE OF INDIA
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The Mining, Geological and Metallurgical Institute of India

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President's Message

Critical minerals : out of the frying pan, into the fire?

Critical minerals have dominated a large part of the discourse in the scientific literature and popular media over the past couple of years. At the Business 20 Summit organized as part of India's G20 Presidency last year, the Hon'ble Prime Minister of India noted that critical minerals should be viewed as the custodianship of global responsibility. He rightly pointed to the risks of an adverse colonial model that could develop for such minerals. Prominent industrialist Mr. Elon Musk has cited lithium as the new oil, and urged entrepreneurs to produce refining capacity. This special issue of the MGMI News Journal aims to understand the drivers to this increased interest in critical minerals.

If we look at what drives the criticality of any particular mineral, the first feature is the functionality of the mineral in meeting energy supply, transmission or demand needs. Thus, minerals required for wind turbines, green hydrogen pipelines, electric vehicle batteries and smart thermostats are all examples where critical minerals are being used or will be used. The second connotation of the criticality is the extent to which the mineral supply-chain is vulnerable to disruption. Disruption may result from physical, financial, and policy-related risks. As such, the definition of critical minerals is dependent, in large part, on the classification made by the agencies within a national government.

In addition to geopolitical disruptions, some environmentalists also view the critical minerals boom with some skepticism. This is because their mining can lead to significant socio-environmental issues well known to metal miners for decades. This has led them to the thinking that the energy transition is a case of "out of the frying pan, into the fire". In their view, environmental hazards such as groundwater contamination and emission of carcinogens may pose similar magnitude risks as greenhouse gas emissions from fossil fuel extraction and combustion. Many of us also remember the oil crises of the early 1970s. At that time, inflation more than tripled during 1972-1974. Such inflation poses a risk to drain the foreign exchange. Does it mean that something has got to give?

My belief is not necessarily. Some features of sustainable development are equally applicable to the critical minerals sector as they are to other aspects of decarbonization discussed in many previous issues of this journal. For example, circular economy thinking mandates that efficiency of our systems improve. Improvement of efficiencies reduces the resource requirement itself. In a similar vein, waste management would need to improve by developing recycling infrastructure for commodities involving critical minerals. Recycling feasibility is directly related to economy of scale. Thus, developing hubs with in large demand centers can make existing approaches more economic. Another approach is substitution. India is already looking to aggressively scale up its green hydrogen infrastructure. If hydrogen propulsion is developed simultaneously, it can reduce the demand for lithium in electric vehicle batteries. The energy transition, therefore, allows us to rethink some traditional notions in engineering.

Stakeholders across India are already taking note of the rising demand for such minerals. The Government of India has identified 30 critical minerals. Many of these minerals such as lithium, cobalt and nickel have large import dependencies. The Government of India has amended the MMDR Act of 1957 through the MMDR Amendment Act, 2023. Among other changes, 24 critical and strategic minerals have been appended to part D to Schedule-I of this act. Several critical mineral blocks have been notified for auction, and royalty rates have also been approved by the Union Cabinet for some of them. One can hope that the strategic planning in this domain will help India reduce its import dependence and strengthen its energy security. The Geological Survey of India also discovered an estimated 5.9 million tonnes of lithium in Jammu & Kashmir, and efforts are underway at the exploratory stage.

In the decade ahead, the new area of critical minerals provides a number of new research topics for young engineers and scientists to work on. A recent report under the auspices of the office of the Principal Scientific Advisor to the Government of India, prepared by the Indian Institute of Management Ahmedabad, takes a deeper look at this sector of the economy. One of its recommendations is to focus on vanadium redox flow batteries. These batteries are characterized by higher recyclability and versatility of sources. Vanadium may be found in the slag produced by iron and steel industries and also crude oil refining facilities. Recovering these trace supplies for electric vehicle charging infrastructure can reduce import dependence. Oil and gas brines are also potential sources of critical minerals. Approaches to recover critical minerals from brine desalinations plants could also prove helpful in the long run.

From the perspective of MGMI Council, I am happy to note the diversification in the themes of special issues over the past two years in line with national requirements. I compliment the Editorial Board led by Dr. Ajay Kumar Singh, and the Guest Editor, Dr. Ajoy Kumar Moitra, for visualizing this special issue. Based on the interview of the Director General, Geological Survey of India, and several thought-provoking articles, the special issue has the potential to be of great importance to policymakers.

Dr. B. Veera Reddy
President, MGMI

Editorial

Critical Minerals : Key to Modern Technology and Green Energy

Critical minerals are essential for modern technology and industry, playing a vital role in sectors such as electronics, energy, and transportation. These minerals, including lithium, cobalt, and rare earth elements, are crucial for manufacturing batteries, renewable energy technologies like wind turbines and solar panels, and advanced electronics. Their availability directly impacts the development of green technolo gies and the transition to a low-car bon energy systems, making them indispensable for sustainable development and economic growth.

The future of the global economy will be driven by technologies that rely heavily on minerals like lithium, graphite, cobalt, titanium, and rare earth elements. They-play a key role in support ing the global shift to wards a low-emission economy, as they are integral to the renew able energy tech nologies needed to achieve the 'Net Zero' goals that more and more countries are committing to worldwide.

Many countries globally including USA, UK, EU, Japan and Australia have identified critical minerals based on their national priorities and future requirements. India, too, has undertaken initiatives in the past to identify the minerals vital for the country, which possesses substantial reserves of essential minerals, such as lithium, cobalt, nickel, and rare earth elements crucial for modern technologies and renewable energy. However, most of these resources remain underexplored and untapped. Key states such as Andhra Pradesh, Rajasthan, Odisha, Jharkhand and Karnataka are known for their mineral wealth, with recent discoveries of lithium in Jammu and Kashmir and Rajasthan sparking interest. The Government of India has launched initiatives like establishment of National Mineral Exploration Trust (NMET) vide Gazette Notification G.S.R.633(E) of 14th August 2015, in pursuance of subsection(1) of Section 9C of the Mines and Minerals (Development and Regulation) Act, 1957, with the objective to expedite mineral exploration in the country.

The removal of six minerals, including lithium from the atomic minerals list of India has opened the door for private players to explore and mine these resources. The government initiated the auction of 20 blocks of critical and strategic minerals and the Critical Minerals Strategy to boost exploration and sustainable mining. Future programmes aim to reduce import dependence, ensure resource security, and promote technological advancements in mineral extraction and processing.

Critical minerals are essential to the energy sector, playing a pivotal role in the transition to renewable energy sources and the development of advanced technologies, which are key to reducing dependence on fossil fuels for low carbon economy. These minerals enable efficient energy storage, power generation, and electric vehicle production, making them crucial for achieving global climate goals. As the demand for clean energy solutions grows, securing a reliable supply of critical minerals has become a strategic priority for many nations including India.

Wind energy is rapidly advancing as a leading clean technology. According to reports from the European Commission and others, the power industry will require extensive adoption of wind technology to fulfil future energy needs through renewable sources. This growing demand for wind turbines will also drive a significant increase in the need for raw materials. Wind turbines are composed of around 25,000 parts, which are organized into key sections such as the tower, nacelle, and rotor. Major components including the tower, nacelle, rotor, and foundation are typically made from steel or stainless steel. The production of steel involves not only iron but also various other metals including nickel, molybdenum, manganese, and chromium. Similarly, the construction of solar PV systems involves a diverse range of materials such as concrete, steel, plastic, glass, aluminium, and copper for their structural and electrical components. Advancements in materials could significantly enhance the efficiency of neodymium use in wind turbines by minimizing dependence on permanent magnets through innovative designs. Adopting hybrid turbines equipped with medium-speed gear boxes and permanent magnet generators could further reduce reliance on neodymium. These improvements have the potential to cut the demand for neodymium in wind energy technology by 45%, relative to the current mineral composition in existing wind systems.

Solar energy has emerged as one of the fastest-growing sources of renewable energy in recent years. This growth is driven by the diverse range of raw materials required for various solar photovoltaic (PV) technologies. Among these, four main types of solar PV technologies are prevalent : crystalline silicon (crystalline Si), copper indium gallium selenide (CIGS), cadmium telluride (CdTe), and amorphous silicon (amorphous Si). Notably, the three thin-film technologies – CIGS, CdTe, and amorphous silicon – are projected to account for an increasing share of the market, potentially rising from 20% to 50% of all solar panels. As a result, there will be a growing demand for materials such as aluminium and indium, which are essential components in CIGS solar cells. This shift highlights the evolving landscape of solar energy technology and the need for specific materials to support its expansion.

Battery storage technology plays a vital role in harnessing energy from intermittent sources like solar panels and wind turbines. It is also essential for operating electric vehicles. Batteries are made up of three core components: the anode, the cathode, and the electrolyte. The types of minerals utilized in these components vary across different battery technologies and within the same type of battery.

Lithium-ion batteries are widely used due to their high energy density. However, limited lithium resources and rising costs are pushing the search for alternative storage solutions. Sodium-ion batteries offer a promising alternative, thanks to sodium's abundance, affordability, and favourable redox potential, making them suitable for both stationary energy storage and electric vehicles. Concerns about lithium's sustainability, along with the high costs and environmental issues associated with mining, highlight the need for new, sustainable storage technologies. The scarcity of transition metals further drive the development of more sustainable alternatives.

Emerging battery technologies include vanadium redox flow, solid-state Li-ion, and zinc-air batteries. Zinc-air options are advancing quickly and may reduce reliance on minerals used in Li-ion batteries, shifting focus to materials like nickel, zinc, and silver. Previously non-rechargeable, zinc-based batteries are now being developed as lightweight, cost-effective, and eco-friendly rechargeable options.

In light of the growing significance of critical minerals across various industries, particularly in the energy sector, we felt it timely to dedicate this special issue to the topic. On behalf of the Editorial Board, I would like to express our heartfelt gratitude to Dr. B. Veera Reddy, Director (Technical), Coal India Limited and President, MGMI, for his unwavering support. I extend my sincere thanks to Dr. Ajoy Kumar Moitra for graciously serving as the Guest Editor for this edition. Our appreciation goes out to Shri Janardan Prasad, Director General, GSI, for his insightful interview with Dr. Moitra, which added depth to our understanding of the subject. We are also deeply appreciative of the valuable contributions from all the authors.

Ajay Kumar Singh
Hony. Editor

GUEST EDITOR'S COLUMN

Editorial Commentary on Critical Minerals

Most of us though heard of it but precisely not knowing its parameters. This never meant to disregard this excellent way of giving boosters to mineral exploration with thrust long awaited.

It is felt that coinage of Critical Minerals possibly remaining an enigma, as propagation to investors especially marginal ones is not adequate. Public consciousness about this wonderful idea is needed to be accelerated.

Idea of taking up critical minerals stems from Energy Act 2020 of USA.

It was defined "any mineral, element substance or material designated as critical by Secretary of the Interior acting through the Director of the US Geological Survey". This is part of international agreement to combat excess carbon emission. India also actively got on to it.

A committee had been constituted on 1st October 2022 in India for identifying Critical and Strategic minerals. A National Institute, Center of Excellence on Critical Minerals (CESM) was formed vested with the responsibility of updating list of critical minerals periodically in India preferably in every three years. A list of 30 minerals was made as critical minerals to initiate. Subsequently, a joint venture company namely Khanij Bidesh India Limited (KABIL) was formed, stake holders being National Aluminium Company, Hindustan Copper Ltd and Mineral Exploration and Consultancy Ltd with the objective to oversee supply of critical minerals including strategic minerals only.

The Government of India subsequently amended the Mines and Minerals Development and Regulation (MMDR) Act 1957 by MMDR Act 2023.

All these actions taken up are praiseworthy with focus on extraction and processing.

Reviews of critical minerals list, periodically, is a practical and welcome move as mineral demand and supply keep changing rapidly and so the priorities.

Many of the minerals listed are somewhat uncommon to investors. For instance, some investors have approached me to learn about glauconite and its applications. It would be prudent and beneficial to include a line or two explaining the uses of these minerals and the potential value added through processing. This is especially true for graphite, where market value can increase rapidly with improvements in fixed carbon content, as well as for lithium, where efficient segregation from its ore – often auctioned can provide investors with a strong incentive to proceed.

Some minerals, such as SMS grade limestone and dolomite, which are fast depleting, need to be added to subsequent lists of critical minerals.

It has been observed that some minerals are 'underused' resulting fast depletion of those valuable minerals which could be utilized in a sustainable way. Chemical Grade Limestone being one, which is being used in many parts for manufacturing grey cement. This is gross underuse. Thus, a very valuable resource is being very fast consumed without putting those to much more useful purpose like medicine.

This volume brings out important facets of Critical Minerals by contributors, well known for their expertise.

I hope this will serve as hand book for both academia and industries.

Dr. Ajoy Kumar Moitra
Guest Editor

IN MEMORY OF LATE DR ANIL KUMAR DATTA (MMGI, LM – 5858)

Late Dr Anil Kumar Datta (MMGI, LM – 5858) passed away on 9th May 2024. With heartfelt grief MGMI members wish his soul to Rest in Peace in his heavenly abode. May God give strength to his surviving family members and friends to bear the loss.

Late Datta became a Life Member of MGMI in 1991-92. Born in April 1935, he obtained B.Sc. (Hons) and M.Sc. (Geology) degrees from Presidency College under University of Calcutta in 1956 and 1958 respectively. He was awarded Ph.D. for his research work on Pegmatites of Rajasthan in 1967.

After a brief stint at Coal Board, Dr Datta joined Geological Survey of India (GSI) as Assistant Geologist in September 1960 and was subsequently promoted to the posts of Geologist (Jr), Geologist (Sr) and Director in 1962, 1966 and 1981 respectively. After his transfer from Northeastern Region he joined Coal Wing as Director, Coal-II Division in 1986. He was promoted to the post of Deputy Director General (Coordination), Coal Wing in August 1992.

Dr Datta was well-known for his excellent performance both as a field geologist and also as a petrologist in the laboratory during his earlier days at GSI. He had not only treaded over vast stretches from the desertic terrains of Rajasthan in the west to lush green northeastern hills of our country, but also through the corridors of geological time from Archean to Tertiary to study the amazing rock records sculptured by nature.

He started his career with base metal investigation at Zawar. He carried out geological mapping in Bharatpur and Sawai Madhopur and studied gossan zones of Khetri belt with a view to locating hidden base metal deposits from surface manifestation. His research work on internal structure, mineralogy and petrography of calc-alkaline pegmatites of Rajasthan during 1962-66 earned him the Ph.D. degree from University of Calcutta and the findings were published in Memoir, Vol 102 by GSI. Another outstanding work of Dr Datta on petrology and geochemistry of ultrabasic and basic igneous complexes of Archean shields of India, as part of International Upper Mantle Project, was published in Memoir, Vol. 100 of GSI.

During his posting at Curatorial Division, Dr Datta was actively engaged in setting up of Geological Museum at GSI Training Institute, Raipur. He was responsible for complete reorganisation, maintenance, upkeep of rock, mineral and meteorite galleries of Indian Museum at Calcutta. His efforts on preparation of detailed scheme for the proposed National Geological Museum at New Delhi and Geological Museum at Nehru Centre, Bombay are worth mentioning.

In Shillong as Director, he supervised projects on Ophiolite Suite in Naga hills, Granitic plutons of Meghalaya plateau, Volcanics of Khasi and Garo hills, Migmatites of Subansiri district and sedimentological studies of Tertiary sediments of Tripura. His work on Ophiolite suite was published in GSI Memoir, Vol. 119 and Journal Geological Society of India, Vol. 30.

At Coal Wing, Dr Datta supervised the exploration work of Bihar and Orissa coalfields and also the Publication Division. During 1989-92, as Director (Planning & Coordination) he assisted Deputy Director General, Coal Wing in finalisation of Master Plan of exploration for Coal and lignite in the country. He also acted as the Member Secretary, Sub-Committee on Coal and Lignite of Central Geological Programming Board. Dr Datta superannuated from GSI in April 1993 after rendering a commendable service for more than three decades.

Dr Datta has written three memoirs published by GSI and 38 scientific papers, which have been published in various acclaimed scientific journals.

His outstanding contribution to Geological Sciences was recognised by the award of Coggin Brown Memorial Gold Medal in 1991-92. Since becoming a member of MGMI he was an active participant in all events and was a Founder Member of the Calcutta Branch. He was the Convener of the National Seminar on 'New Finds of Coal in India – Resource potential and Mining Possibilities' organised by MGMI at Taj Bengal, Calcutta in 1993. The 6th edition of 'Indian Mining Directory' published by MGMI in 2006 was prepared under his convenership. In the early years of Calcutta Branch of MGMI, his active involvement in organizing its flagship event, Annual Get-together, will be remembered for long.

Dr Datta at National Seminar on 'New Finds of Coal in India – Resource Potential and Mining Possibilities' organised by MGMI in 1993

An able scientist and administrator, his door was always open to anyone who wanted any help or advice. A genial personality, he seldom lost his cool and his smile.

MINUTES OF THE 901ST MEETING OF THE COUNCIL

(Held through Hybrid mode in Physical and Virtual Platform through Zoom)

Date & Time : Sunday, 3rd December 2023 at 11:30 A.M.

The report of the **901st Council Meeting** (1st meeting of the 118th Session) at **MGMI Building,** GN-38/4, Sector – V, Saltlake, Kolkata – 700091 on Sunday, **3rd December, 2023 at 11.30 a.m.** (duly approved in the 902nd Council Meeting held on 27th April 2024).

Present : Dr. B Veera Reddy, President in the Chair on Virtual. The meeting was attended by Prof Sakti Pada Banerjee, Prof B B Dhar (Virtual), S/Shri N C Jha, J P Goenka, Rajiw Lochan (Virtual), Prasanta Roy, Dr. Chandra Shekhar Singh (Virtual), Dr. Prabhat Kumar Mandal, Dr Ajay Kumar Singh (Virtual), V K Arora, Prof. Bhabesh Chandra Sarkar, Awadh Kishore Pandey (Virtual), Peeyush Kumar (Virtual), Prof. G.P. Karmakar, N N Gautam (Virtual), Dr. Kalyan Sen, Prof. N C Dey, Dr J P Barnwal, Thomas Cherian (Virtual), Prof. Ashish Bhattacharjee, Dr. Amalendu Sinha, Prof. Rajib Dey, Dr.Ajoy Kr Moitra and Ranajit Talapatra.

ITEM No. 0 Opening of the Meeting

0.1 Sri Ranajit Talapatra, Honorary Secretary welcomed all members present physically as well as virtually and requested the President to call the 'meeting to order' and addressthe council members.

0.2 The President welcomed all those present physically and virtually in the meeting.

The President congratulated the Council members of MGMI and thanked TAFCON for successfully holding the 10th AMC and IME in November, 2023 at Kolkata. He emphasized that MGMI activities needed to be boosted up in the Mining Sector.

He requested Honorary Secretary to start with the agenda of the meeting.

The Honorary Secretary expressed gratitude to the President and proceeded with the meeting following the Agenda items one by one.

The Honorary Secretary and the Council welcomed a new Member – Prof. Rajib Dey

He also informed of the death of Shri B.R. Prasad and a one minute silence was observed in his memory. Prof. S.P. Banerjee and Shri J P Goenka spoke about of Late B R Prasad.

Regarding holding of Golf Tournament, the President highlighted that the last month (November 2023) was busy due to 10th AMC & IME and he informed that efforts will be made to organise the tournament in MCL in the month of January or February 2024.

901.1.0 To confirm the Minutes of the 900th meeting of the Council held in Hybrid platform at MGMI Hqs, Sector- V, Salt Lake, Kolkata on 2nd September, 2023 at 14:30hrs.

The 900th Council Meeting Minutes had been circulated via mail to all the Council Members and in the absence of any comments received,the Councilresolved that :

Resolution : The Minutes of the 900th (6thmeeting of the 117th Session) meeting of the Council held on 2nd September, 2023 at 14:30hrs. be confirmed.

901.1.1 To consider matters arising out of the Minutes.

The Honorary Secretary read out the ATR (Action Taken Report) in respect of the Minutes of the 900th Council meeting.

The Council considered the Action Taken Report in respect of the Minutes of 900th Council Meeting held on 2nd September, 2023 held in Hybrid platform and concurred.

He also informed that the Decision of the Scrutineers' Committee for election of one vacant Metallurgist Seat in MGMI Council for the term 2023-26 where Prof. Rajib Dey was chosen & has been announced during the 117th AGM held on 23rd September, 2023 in Kolkata. Prof. Rajib Dey introduced himself to the Council.

901.2.0 To discuss Report about the 10th Asian Mining Congress and Exhibition.

The Honorary Secretary informed the Council members that the 10th AMC & IME were held successfully in the month of November 2023 in Kolkata.

The President requested that MGMI should try to focus on the 5 points that the Secretary, Ministry of Coal raised during his inauguration speech as Guest of Honour and suggested that they may be looked into by MGMI for implementation, if possible. The Honorary Secretary informed that during the 8th meeting of the Technical Committee of 10th AMC held at MGMI office on 2nd December, 2023, discussions were held on these points. He informed that the recommendations will be prepared soon and the Chairman of the Technical Committee will elaborate on these matters later.

The Honorary Secretary apprised that a small video clip showcasing the key moments of the event as well as a 1-minute clip on IME are on the Facebook but as MGMI X (Twitter) handle is not allowing uploading of such big videos, they could not be posted there. The President suggested having a media committee to handle these things and if necessary, employ some agency for professional help.

The Honorary Secretary on behalf of Shri Wadhwa and Dr. C.S. Singh, (Honorary Jt Secretary who was not present) informed the Council Members that in the 10th IME - 370 stalls were sold, including 130 outdoor stalls. He expressed his views that this time more amount will be payable by TAFCON over and above INR 55 Lakhs guaranteed amount. On a query by Sri J P Goenka the council was informed that though the final figure seemed to be above 70 Lakhs, but it was not finalised perhaps and the Convener, IME may have access to the actual amount. However, Dr C S Singh was not present or logged in and could not be contacted.

The Honorary Secretary thanked the Chairman of the Exhibition Committee – Shri Bhola Singh, Co- Chairman- Shri J P Goenka, Convenor, Dr. C. S. Singh, Shri V K Arora and others including the TAFCON management for organizing the 10th IME so successfully.

The Honorary Secretary requested the Convenor, Conference Shri Prasanta Roy to apprise the council about the 10th AMC.

The Convenor, Conference, Shri Prasanta Roy, shared his views that the 10th AMC & IME were held successfully in November 2023. He informed that this time almost all Mining Companies have participated. He also informed that the Secretary, Ministry of Coal had participated in the inaugural session. The Secretary, Ministry of Mines was the Chief Guest in valedictory session. He further informed that this time there were many foreign participants mainly from Australia and Germany. Approximately 500 attendees were present, 08 keynote addresses were given and 58 papers were presented. He also informed that during this time and for the first time, papers were published by globally renowned Publishers Springer Nature. He thanked the Technical Committee for successfully executing this project. He also informed that in the CEOs session many mining Companies and other Companies were present and also for sponsorship many mining Companies and other Companies played good role and contributed well.

The Honorary Secretary requested the Chairman of Technical Committee Dr. Amalendu Sinha to apprise the Council about the Main AMC technical sessions.

Dr. Amalendu Sinha in his address to the Council mentioned about the help he received from all members of the Technical Committee and the Council and informed that out of 58 papers finalised, 52 were actually presented along with 7 Keynote papers. Dr Nanda's keynote could not be presented as he could not attend the Conference.

He said that it was the first time that the proceedings were published by Springer Nature and was temporarily downloadable from a link shared with the authors and delegates. He thanked Dr Bhabesh Ch. Sarkar and Dr P K Mondal for helping him in taking out the Springer Proceedings.

Prof. S. P. Banerjee, commended the collaborative efforts of the team, expressing admiration for their outstanding work.

901.3.0 To elect office bearers viz Vice Presidents, Hony Jt. Secretary, Hony Treasurer and Hony Editor amongst the New Council Members of the Institute for the year 2023-24.

The Honorary Secretary informed the Council members the names of the existing Vice Presidents for the respective regions and also the names of existing other honorary posts as hereunder :

North – Shri Bhola Singh.

East – Shri J P Goenka.

South – Shri J.V. Dattatreyulu.

West – Shri Thomas Cherian.

Honorary Joint Secretary – Dr. C. S. Singh.

Honorary Treasurer – Dr. Prabhat Kr Mandal.

Honorary Editor – Dr. Ajay Kr Singh.

The Council approved for continuation of the above gentlemen for the year 2023-24.

901.4.0 To review and consider the proposed Budget for the year 2023-24.

The Honorary Secretary discussed the budget at the Council Meeting and also highlighted that this year meeting expenditure had gone up due to Foundation Day event and other events hosted in Kolkata. Shri Prasanta Roy also explained that the AGM in September 2023 was held along with a half day national seminar GMANZ-2023 and as no sponsorship was taken in view of the forthcoming 10th AMC, the expenditure had increased substantially. It was also informed that refurbishment of Transit house had to be made because of non-use for two years of Covid. It was informed that advertisements in the website and in the social media are being put up periodically about availability of the MGMI Transit House once more. He also highlighted the expenditures incurred under other heads to the Council Members.

He also mentioned that a roof shed has to be set up and for this a good amount of expenditure to the tune of about INR 12-13 lakhs would be needed. The council agreed to Capital expenditures for increasing or overhauling / refurbishing MGMI assets.

The President advised to break the tradition of handing the budget copy in the meeting itself as several members were attending online nowadays and suggested that the budget may be circulated through e-mail 2-3 days before the meeting for the members to be apprised.

Shri Peeyush Kumar laid stress on preparing budgets considering future planned events. Shri Prasanta Roy mentioned that whenever any programme is held it should be self-sustainable and full efforts should be directed towards that goal. The event should not be organised from saved funds unless extremely necessary and hence this budget, which is an administrative one, should not contain such projections.

Shri N C Jha suggested that the next financial year's budget to be prepared and approved in early around March-April for that particular year. Shri Prasanta Roy re-iterated that the budget placed before the Council is for MGMI general administration purpose.

901.5.0 To discuss about Future events.

Honorary Secretary informed the Council Members that the Nagpur Chapter of MGMI is to organize an event on 20th December 2023. Shri Thomas Cherian said that he intended to hold a program in the western part of the country – Mumbai, Pune preferably early during Feb - March 2024. He will plan the event and give the President a clear picture later.

He also informed that he had spoken with the Director, ECL regarding the Foundation Day program in January 2024, if possible and that he has requested ECL to make arrangements if held in Sanctoria. However, a speaker was to be identified who was ready to travel to Sanctoria. Dr A K Moitra suggested the name of Dr. Kalyan Rudra, who is the Chairman of State PCB, Government. of West Bengal.

Prof. S.P. Banerjee expressed his views that three-four decades ago, MGMI had a lot of rapport with the Governments and was consulted in many policy matters on Mining and Earth Sciences. He requested the Council members to take steps to revive the rapport with the Governments. The President proposed the formation of a committee comprising senior and well-connected members, during the upcoming Council Meeting. The purpose of the committee would be to brainstorm and strategize on ways to revitalize MGMI.

901.6.0 Toconsider applications for membership and membership position of the Institute

The Honorary Secretary informed that total 36 applications were received and out of which 33 are for Life Membership and 3 for Membership.

The President emphasized the need for an increase in new membership applications to a minimum of 100 at each Council Meeting.

The Honorary Secretary informed that one membership application pertains to a Finance Officer working in MCL, who is not eligible for Life Membership as per the present Educational qualification criteria having only degrees in Finance. He suggested that the Council accept him as an Associate member. He proposed to review rules laid in AoA and to set up a committee comprising Shri N C Jha, Shri J P Goenka, Shri V K Arora and Shri Prasanta Roy. The Committee will make changes in the clauses and thereby adapting to the new digital practice of e-voting and also to change the existing rules for eligibility criteria and get it approved in the next AGM.

Membership Position
(As on 03.12.2023)

	02.09.2023	Add	Trans	Loss	03.12.2023
Member	42	03	-	-	45
Life Member	2128	32	-	-	2160
Associate	19	01	-	-	20
Student Associate	06	-	-	-	06
Life Subscriber	27	-	-	-	27
Subscriber	01	-	-	-	01
Life Donor	01	-	-	-	01
Donor	01	-	-	-	01
Patron	05	-	-	-	05
Corporate	07	-	-	-	07
Life Corporate	02	-	-	-	02
	2239	36			2275

901.7.0 Any other matter with the permission of the chair.

a. A working group of interested members of MGMI along with a few non-members, having expertise on various related subjects, met several times in Kolkata and also via virtual meetings to draft a proposal on the Role of MGMI in helping Government of India achieve Net Zero Objectives by 2070.

The Group consisted mainly of retired persons like S/Shri Parthasarathi Bhattacharya, N C Jha, Dr Asesh Lahiri, CCF, Consultant, FAO, R N Sen, ED, NTPC and Chairman, DVC, S P Chakraborty, CGM, BSNL, Dr A K Singh, present Executives of MGMI et al.

The crux of the proposal centred around the idea of conducting workshops and training classes targeted at Industry executives and/or Supervisory Staff by the members of the group with relevant expertise, with MGMI arranging for the fund, logistics and infrastructure.

The Honorary Secretary sought advice from the President who requested

Dr. Kalyan Sen to prepare detailed background notes and circulate to all members and discuss in the next meeting about the feasibility and practical utility of such training workshops in making itself more acceptable to the Government of India.

Shri Prasanta Roy reiterated that if such a programme is organized under the aegis of MGMI, is it should be sustainable from all fronts including all TA, DA etc. and it should not be expected that the funding will be by MGMI. However, MGMI will provide its infrastructure like halls, rooms, etc.

Other members held the opinion that a concrete and detailed proposal has to be made out delineating the advantages to MGMI and revival of leverage with the government.

Considering the views of several members, the discussion was deferred.

b. Shri Peeyush Kumar volunteered that he will prepare a policy paper regarding how MGMI can play a role and share the same with Niti Aayog, Ministry of Mines and Ministry of Coal.

The President requested someone to take up the responsibility of handling the social Media and Shri Peeyush again volunteered for the same.

c. Shri Bhaskar Chakraborty shared information with the Council members that MGMI Calcutta branch will hold an annual day on 7th January 2024 (Sunday) and invited all the members to join and also requested the Council to sponsor a disabled child.

d. The Honorary Secretary also informed the Council members that as per discussion in last Council meeting, the Company Secretary identified for MGMI has brought down his rate from 18000 per month to 12000 after negotiations. He requested the Council to approve the appointment of Shri Md Menazuddin, a qualified Company Secretary on retainership at negotiated fees of Rs.12,000/- per month. It was informed that he will come 1 day in a week on routine visits other than specific needs. He will also take care of e-voting process through CDSL or any other reputed agency on advice of MGMI. The Council, after discussions, approved his appointment.

e. The President stressed the need to expedite recommendations after every seminar/conference and circulate to relevant authorities and make them public. He entrusted the Honorary Editor to do so after each seminar other than the AMCs in which case it would be the responsibility of the Technical Committee.

The meeting ended with Vote of Thanks to the Chair and others present both physically and virtually by the President and Honorary Secretary.

MINUTES OF THE 902nd MEETING OF THE COUNCIL

(Held through Hybrid Mode in Physical and Virtual Platform through Zoom)

Date & Time : Saturday, 27th April 2024 at 03:00 P.M.

The report of the 902nd **Council Meeting** (2nd meeting of the 118th Session) at **MGMI Building,** GN-38/4, Sector – V, Salt Lake, Kolkata – 700091 on Saturday **27th April 2024 at 3.00 p.m.** (duly approved in the 903rd Council Meeting held on 22nd June 2024).

Present : Dr. B Veera Reddy, President in the Chair on Virtual. The meeting was attended by Prof Sakti Pada Banerjee, S/Shri R P Ritolia, R. K. Saha, J P Goenka, Rajiw Lochan (Virtual), Prasanta Roy, Dr. Chandra Shekhar Singh, Dr. Prabhat Kumar Mandal (Virtual), V K Arora, Dr. Amalendu Sinha, Prof. Bhabesh Chandra Sarkar, Awadh Kishore Pandey (Virtual), Prof. G. P. Karmakar (Virtual), N N Gautam (Virtual), Dr. Kalyan Sen, Prof. N C Dey, J V Dattatreyulu (Virtual), Thomas Cherian (Virtual), Prof. (Dr.) Rajib Dey and Ranajit Talapatra.

ITEM No. 0 Opening of the Meeting

0.1 Sri Ranajit Talapatra, Honorary Secretary welcomed all members present physically as well as virtually and requested the President, who was attending virtually, to call the 'meeting to order' and address the council members.

0.2 The President welcomed all those present physically and virtually in the meeting and granted leave of absence to those who could not be present.

The President congratulated the Council members of MGMI and thanked Shri JP Goenka for holding the Golf Tournament at RCGC, Kolkata successfully on 24th April 2024.

He also told that due to some unforeseen circumstances the Foundation Day Lecture along with the 902nd Council Meeting (02nd Meeting of the 118th Session) could not be held at ECL, Hqs, Sanctoria, Asansol on 17th Feb, 2024 at 12:00 Noon

He requested Honorary Secretary to start with the agenda of the meeting.

Honorary Secretary thanked the President and proceeded with the meeting following the Agenda items.

902.1.0 To confirm the Minutes of the 901st meeting of the Council held in Hybrid platform at MGMI Hqs, Sector - V, Salt Lake, Kolkata on 3rd December, 2023 at 11:30am.

The Minutes of the 901st Council Meeting had been circulated via mail to all the Council Members and changes suggested by Honorary Editor, have been duly incorporated and shared with the 902nd Council Meeting Notice on 13.04.2024.

The Council resolved that :

Resolution : The Minutes of the 901st (1st meeting of the 118th Session) meeting of the Council held on 3rd December, 2023 at 11:30 am be confirmed.

902.1.1 To consider matters arising out of the Minutes.

The Honorary Secretary read out the ATR (Action Taken Report) in respect of the Minutes of the 901st Council meeting.

The Council considered the Action Taken Report in respect of the Minutes of 901st- Council Meeting held on 3rd December, 2023 in Hybrid platform and concurred.

Events in the first 4 months of 2024 were discussed. MGMI Western / Nagpur Chapter organised a National Seminar on Artifical Intelligence in Mining

(AIM) on 26.2.2024 at Sofitel, Mumbai. Secretary thanked Mr Thomas Cherian for taking the initiative and organising it at such a short time. Honorary Secretary also thanked Shri N N Gautam and MGMI Delhi Chapter for successfully organisingthe 8th Round Table Conference on Coal on the theme - "Role of Coal in Energy Transition" in association with ISM Alumni Association and India Energy Forum on Friday, 12th April 2024 at Hotel Le Meridien, New Delhi.

Mr Cherian thanked the President for being the Chief Guest in AIM 24 and also the Honorary Secretary, especially for undertaking all efforts in helping to plan the theme & flow and organise the event in short time remotely from Kolkata, liaising with WCL Nagpur Chapter, pursuing for sponsorships and getting some of the speakers.

It was also suggested by members of the Council to publish MGMI newsletter and MGMI Journal separately. As Honorary Editor was not present, the council requested Secretary to include this in the minutes and apprise Honorary Editor for proceeding on that line, if not in the next issue but thereafter.

Also, Council Members discussed about exploring how to publish the journal on Springer Platform to attract good authors and higher quality articles to MGMI journal. It was unanimously agreed that this will lead to MGMI Journal being a coveted place to publish related articles/ papers, etc.

It was advised to correspond with Springer for publishing the MGMI Journal through Springer platform. It was also suggested that the editorial team will contact Springer for publishing including terms and conditions for the same. The editorial team should take help of the team that took the successful initiative to publish 10th AMC proceedings through Springer and also from Institute of Engineers (India) who are already publishing their journals through Springer.

902.2.0 To review and consider the proposed Budget for the Council Year 2023 - 24 (Sept 2023 - Sept 2024)

The estimated budget for the FY 2023-24 was placed before the council members for their review, consideration & approval.

The proposed budget includes allocations for various departments including administration, maintenance, legal, accounts & others. Each department's budget was based on historical data, anticipated expenses and proposed initiatives for the upcoming year.

The members discussed the matter at length and considered the proposed budget and it was passed by the Council for Council Year FY 2023-24 (Sep 23 - Sep 24).

902.3.0 To discuss about the future events of the Institute

Honorary Secretary informed the Council Members that as per desire of President, the long pending Foundation Day Lecture) is proposed to be held in Asansol to be delivered by Chairman, DVC who had agreed for the lecture.

Also, it was proposed by Honorary Secretary that Prof. (Dr.) Rajib Dey is named as the Convener of the Yearly Half Day Seminar that usually take place before AGM in Sept 2024. The AGM date was tentatively scheduled on Saturday, the 21st of September 2024.

A workshop of 4-5 days with CIMFR on a suitable topic was also proposed by Dr Amalendu Sinha who reminded that an MOU exists and it needs to be implemented. Sri Prasanta Roy was requested to organise the Workshop in tandem with CIMFR with lectures in Kolkata and Field Visit to Dhanbad.

902.4.0 To consider and constitute a Board of scrutineers to conduct the Election of Council Members for the year 2024-27.

The Honorary Secretary informed the Council members that 9 council seats are to go for election and he read out the names of the Council Members whose terms were getting over this September, which are as follows :

- Dr. Kalyan Sen 2021-24
- Shri Pravat Ranjan Mandal -do-
- Shri Anup Biswas -do-
- Shri Nitya Nand Gautam -do-
- Shri Bhaskar Chakraborti -do-
- Dr. Netai Chandra Dey -do-
- Dr. Bhabesh Ch. Sarkar -do-
- Dr. Chandra Sekhar Singh -do-
- Dr. Ajay Kr Singh -do-

He proposed a Committee for the above purpose comprising Shri J P Goenka, Shri V. K. Arora, Dr. Amalendu Sinha and Shri Prasanta Roy (Secretary as an ex-officio member) and the Council Members concurred. It was suggested that as far as possible, the system of e-voting started in 2021 should be continued with the same agency CDSL which is well trusted all over the country.

902.5.0 To consider applications for membership and membership position of the Institute

It was informed that a total of 33 applications were received for Life Membership out of which 1 was for upgradation from Annual Member.

It was pointed out that one membership application pertained to an Officer working in MCL as Manager (Public Relations), namely Shri Vinayak Dwarkanath Sharma Jamwal. The Council was requested to decide whether to accept his application for Life Membership as the Educational Qualification (B. Sc with Chemistry, Zoology & Botany followed by Master of Mass Communication, MBA in HR & Mktg and Advanced Diploma in Margketing Mgmt) and experience (Not in Mining but as PRO in a Mining Company) was completely at variance with the Criteria of Qualification and Experience presently in MGMI MoA &AoA.

After detailed deliberation, it was decided by the Council that his application may be kept in abeyance and his money fully refunded with a polite explanation. His case will be taken up in the AGM after the Council places the recommendations of the committee set up for modifying and updating the AoA and its clauses.

Membership Position
(As on 27.04.2024)

	03.12.2023	Add	Trans	Loss	27.04.2024
Member	45	-	-	-	45
Life Member	2160	32	-	01	2191
Associate	20	-	-	-	20
Student Associate	06	-	-	-	06
Life Subscriber	27	-	-	-	27
Subscriber	01	-	-	-	01
Life Donor	01	-	-	-	01
Donor	01	-	-	-	01
Patron	05	-	-	-	05
Corporate	07	-	-	-	07
Life Corporate	02	-	-	-	02
	2275	32		01	2306

902.6.0 Any other matter with the permission of the Chair.

(i) Secretary informed that in different documents of MGMI, the names are appearing differently. In Certificate of Registration under Companies Act, when the word "Metallurgical" was added to the namein 1937 and in Registration for Income Tax in 1984-85, it is "Mining, Geological & Metallurgical Institute of India", whereas in PAN Card documents and GST Registration it is "The Mining, Geological & Metallurgical Institute of India", which creates a mismatch that is flagged by the Online Payment Gateway Companies as it goes against the SOP of their verification process set up as per RBI mandate. He said that the CA and the Company Secretary both suggested a Council Resolution to change the name from "The Mining, Geological & Metallurgical Institute of India" in PAN and GST to "Mining, Geological & Metallurgical Institute of India".

Accordingly, the 902nd MGMI Council resolved that

a) The name of the Organization, that is "Mining, Geological & Metallurgical Institute of India"or MGMI in common parlance may be corrected in the PAN related documents as well as the GST documents and

b) Honorary Secretary is empowered to sign on behalf of the Council and

c) The Company Secretary and CA will be assigned with the responsibility of carrying out this job under guidance from Honorary Secretary, MGMI

(ii) It was informed that the committee that has been set up for making changes in the clauses to adapt to e-voting processes as per Company Act and to review, if necessary, the existing eligibility criteria for Membership of MGMI had its 1st Meeting on 06th April 2024 (Saturday) at 11:30 am at MGMI Headquarters, Kolkata.

(iii) Shri Prasanta Roy again raised the matter of reviewing the Awards of Excellence in that there should be a separate award for excellence in Geology, as MGMI was founded on Mining and Geology. The Award of Excellence for Earth Sciences will encompass Metallurgy, Ore Dressing / Mineral Processing and others.

The Council suggested that a committee may be constituted to have a re-look at these big awards. The names proposed were those of Shri N C Jha, Dr Amalendu Sinha, Prof Rajib Dey, Dr C S Singh and Shri Prasanta Roy.

It was decided to schedule the next council meeting at Sanctoria along with the 19th Foundation Day Lecture whenever it is held.

The meeting ended with Vote of Thanks to the Chair and others present both physically and virtually by the President and Honorary Secretary.

Theme of the Next Issue of MGMI News Journal

Vol. for 50, No . 2

"Carbon Capture Utilisation and Storage"

NEW MEMBERS

(As approved in Council Meeting on 27.04.2024 and 22.06.2024)

Shri Sonu Kumar Jha - LM-11126
Dy. Manager (Mining), ECL
Eastern Coal fields Ltd
Room-13, HRD Guest House, Dishergarh,
Paschim Burdwan - 713333, West Bengal
(M) 9434796631/8412873344
Email : sonukr.jha@coalindia.in
snjha456@gmail.com

Shri Ankush Priyadarshi - LM-11127
Asstt. Manager (Geology)
Mahanadi Coalfields Ltd
B172, Ananda Vihar, MCL, Birla, Sambalpur,
Odisha – 768 020, (M) 9437953911
Email : ankuss.2594@gmail.com
ankush.priyadarshi@coalindia.in

Shri Deepak Kumar - LM-11128
Dy. Manager (Mining)
Eastern Coalfields Ltd
Room No. 353, CMC Deptt, ECL Hqs.
Director (Technical) Building, Sanctoria,
West Bengal – 713333
(M) 9434795674/7872377161
Email : deepak060849@gmail.com
deepak.kumar@coalindia.in

Dr. Ankush Galav - LM - 11129
Research Associate, IIT (BHU)
UST, Deptt. of Mining Engineering
IIT (BHU), Varanasi, Uttar Pradesh
Pin - 221 005, (M) 9414488257
Email : ankushgalav.rs.min17@iitbhu.ac.in

Dr. Jai Prakash Patel – LM - 11130
Manager (Coal Preparation), SECL
South Eastern Coalfields Ltd
Room No. 07, Executive Hostel,
Vasant Vihar, Bilaspur
Chhattisgarh – 495 006, (M) 9199107313
Email : jaiprakash.patel@gmail.com

Shri Manish Kumar Srivastava - LM - 11131
General Manager (Mining), SECL
TS to CMD, SECL
South Eastern Coalfields Ltd
A-405, Amba Park, Lingiyadih
Bilaspur, Chhatisgarh – 495 006
(M) 9425531265
Email : manish93@gmail.com

Shri Manish Kumar Baranwal – LM- 11132
Dy. Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr. No. C/07/26, Jhalbagan Colony,
Near DPS More, Sanctoria,
PO. Dishergarh, Paschim Bardhaman
West Bengal – 713333
(M) 9434795580/9002338899
Email : manishtea@gmail.com
manish.baranwal@coalindia.in

Shri Abhijit Bhattacharya - LM- 11133
General Manager (Mining), TS to DT (O)
South Eastern Coalfields Ltd
F-21, Vijyapuram, Seepat Road,
Bilaspur, Chhatisgarh – 495006
(M) 9300311394
Email : abcil_1991@rediffmail.com

Dr. Anup Krishna Prasad – LM-11134
Associate Professor, IIT(ISM), Dhanbad
IIT (ISM), Dhanbad
Department of Applied Geology, IIT(ISM)
Dhanbad – 826004, (M) 9471192451
Email : anupiitk@gmail.com

Imam Naque – LM-11135
Dy. Manager (Mining), ECL
Eastern Coalfields Ltd, HQs.
C5/3E, Sugam Park, South Dhadka
Asansol, Paschim Burdwan – 713302, WB
(M) 9434796256/8145690869

Email : n.imam069@gmail.com
naque.imam@coalindia.in

Shri Sailesh Kumar - LM - 11136
Chief Manager (Mining), CCL
Central Coalfields Ltd
Maitri Marg, Beside Annapurna Enclave
Bariatu Housing Colony, Post - Bariatu
Dist : Ranchi, Jharkhand - 834 009
(M) 9006499980
Email : sk.shailesh.sk@gmail.com

Shri Girish Kumar Rai - LM-11137
Chief Manager (M), SECL
South Eastern Coalfields Ltd
D/12A, Pragati Nagar, Dipka
Dist. Korba, (C.G), Pin – 495452
(M) 9424268821
Email : gkrai7020@gmail.com

Shri Ujjwal Abhishek - LM - 11138
Dy. Manager (Mining), ECL
Eastern Coalfields Ltd
C-311, 1st Floor, Greenfield Complex
Gopalpur, Asansol – 713304,
Dist – Paschim Burdwan, W.B.
(M) 9434795484
Email: ujjwal.abhishek@coalindia.in

Shri Praveen Kumar - LM - 11139
General Manager (Mining)
TS to DT (P&P), SECL
South Eastern Coalfields Ltd
Qtr. No. D-04, Indira Vihar Colony,
Nutun Chowk, Sarkanda, Seepat Road,
Bilaspur, Chhattisgarh – 495006
(M) 9425531707
Email : praveen.1042000@gmail.com

Shri Ajay Kumar - LM - 11140
General Manager (Mining), SECL
South Eastern Coalfields Ltd
Qtr.No. D-4, Kotma Colliery Township
Bhalumada, Near VVIP Guest House
Anuppur, Madhya Pradesh – 484 336
(M) 7415490177
Email : ajay272552@rediffmail.com

Shri Niranjan Rukmangad – LM - 11141
General Manager (Mining), NCL
Northern Coalfields Ltd
Qtr. No. D-503, Shringavali Heights,
Ceti Residential Complex, P.O. Morwa,
Dist – Singrauli, Madhya Pradesh – 486889
(M) 8085336798
Email: nrukmangad@gmail.com

Shri Pradip Kumar – LM - 11142
General Manager (Mining), SECL
South Eastern Coalfields Ltd
GM Bunglow, Shaktinagar, Jarhi Colony
P.O. Bhatgaon Colliery, Dist – Surajpur
Chhatisgarh – 497235, (M) 7000792775
Email : pradipkmr64@gmail.com

Shri Pradip Kumar Thakur – LM - 11143
Ex-General Manager (SAIL)
Steel Authority of India Ltd
Flat No. 1A, DB-65, Street No. 292,
New Town, North 24 Parganas
Kolkata – 700156, (M) 8986880470
Email : pradip_t@rediffmail.com

Dr. Sanjay Kumar Palei – LM - 11144
Associate Professor (IIT-BHU), Varanasi
Department of Mining Engineering
IIT(BHU), Varanasi – 221005, Uttar Pradesh
(M) 9415385467
Email : skpalei.min@iitbhu.ac.in

Shri Lakkarsu Krishna – LM - 11145
Faculty – Engineering Staff College of India
Engineering Staff College of India
Flat No. 101, 1st Floor, Sri Laxmi Nilayam,
Road No. 4, Laxminagar Colony, Miyapur
Hyderabad – 500049, (M) 9553939316
Email : lakkarsukrishna7777@gmail.com

Shri Satya Narain Kapri – LM - 11146
Director Technical (Operations), SECL
South Eastern Coalfields Ltd
SECL-HQ, Seepat Road, Bilaspur,
Chhatisgarh – 495 006, (M) 9474378573
Email : snkcil@gmail.com

Shri Prabhakar Ram Tripathi - LM - 11147
General Manager (Mining), SECL
South Eastern Coalfields Ltd
Qtr,No.D/7, No. 03 Officer Colony
At & P.O. Dhanpuri, Distt. Shahdol
Madhya Pradesh – 484 114, (M) 7319483151
Email : prabhakar.tripathi@coalindia.in

Shri Manoj Bishnoi – LM - 11148
General Manager (Mining), SECL
South Eastern Coalfields Ltd
General Manager Bunglow, Mines Rescue Station Colony, Amakherwa
P.O. Manendragarh, Dist - M.C.B
Pin – 497442, Chhatisgarh, (M) 9754996967
Email : manoj.bisjnoi@yahoo.com

Shri Ritesh Sobti - LM - 11149
General Manager (Mining) SECL
South Eastern Coalfields Ltd
House No. 55, Saroj Vihar, Bahatarai Road, Bilaspur, Chhatisgarh, Pin – 495 006
(M) 9425531704
Email : riteshsobti@gmail.com

Shri Arvind Jha - LM - 11150
GM (Mining), SECL
South Eastern Coalfields Ltd
D1, Urja Nagar, P.O Bhatgaon,
Dist – Surajpur, Chhatisgarh, Pin -497235
(M) 8292632842
Email : bloominglotus67@gmail.com

Shri Atul S B Singh - LM - 11151
General Manager (Mining), SECL
South Eastern Coalfields Ltd
D-62, Vasant Vihar Colony, SECL,
Seepat Road, PS - Sarkanda,
Bilaspur – 495006, Chhatisgarh
(M) 9518715839
Email : atulsbsingh@gmail.com

Dr. Gopesh Dwivedi - LM - 11152
Chief Manager (Mining), WCL
Western Coalfields Ltd
C-43, WCL Sasti Colony, P.O. Rajura
Dist – Chandrapur, Maharashtra – 442905
(M) 9425219479
Email : dgoffice1947@gmail.com

Shri Arvind Kumar - LM - 11153
Chief Manager (Mining), CCL
Central Coalfields Ltd
E-43, Sector – 41, Noida,
Dist : Gautam Budh Nagar, UP – 201 303
(M) 9431106073
Email : arvind0704@gmail.com

Shri Badal Manna - LM - 11154
General Manager (Mining), CMPDIL, CMPDIL
B-97, Rama Green City, Seepat Road,
P.O. SECL, Bilaspur, Chhatisgarh
Pin – 495006, (M) 9424146775
Email : badalmanna@gmail.com

Shri Jatin Mehta - LM - 10890
Director, Cannon Devices Pvt. Ltd
Flat 9B, Neel Kamal, 41, Elgin Road
Kolkata – 700020, (M) 9830046800
Email : jatin.mehta@cannondevices.com
(Transferred from Member to Life Member)

Shri Anil Jain - LM - 11155
Chief Manager (Mining), SECL
South Eastern Coalfields Ltd
D-37, Vasant Vihar Colony, SECL
Bilaspur, Chhatisgarh – 495 006
(M) 9406960598
Email : aniljain994@gmail.com

Shri Bhagwat V Haste - LM - 11156
Chief Manager (Mining), SECL
South Eastern Coalfields Ltd
Qtr. No. D-2, Adarsh Colony, Amadand,
P.O. Chukan, Th-Kotma, Dist – Anuppur
Madhya Pradesh – 484446, (M) 9673506288
Email : b.haste@rediffmail.com

Shri Abhay Balwant Bhagat (LM-11157)
General Manager, NLC
NLC India Limited
402, Kushabhadra A, Greater Sambalpur,
Sambalpur, Odisha – 768004
(M) 9650302081
Email : abhaybb8170@gmail.com

Shri Ishan Goyal (LM - 11158)
Sr. Manager (Mining), ECL
Eastern Coalfields Ltd
Flat 1A, Tower 5, Genex Exotica,
Asansol – 713304, West Bengal
(M) 9434796704/9877748153
Email : ishangoyal2290@gmail.com
ishan.goyal@coalindia.in

Shri Yadu Nandan Paswan (LM - 11159)
Dy. Manager (Mining), ECL
Eastern Coalfields Ltd
Baijnath Appartment, S.F. Road, Durgamandir,
Asansol, P.O. Ushagram
Dist : Paschim Bardhaman
West Bengal – 713302
(M) 9434796440
Email : yadunandanpaswan13@gmail.com

Shri Navin Kumar (LM - 11160)
Manager (Satgram Projects), ECL
Eastern Coalfields Ltd
Manager Satgram Projects,
P.O. Devchandnagar,
Dist-Paschim Bardhaman,WB – 713332
(M) 8789138836
Email : nk461982@gmail.com

Shri Sandip Sarkar (LM - 11161)
Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr. No. 16(A), D Type, Kopeu Colony
P.O. Devchandnagar,
Dist - Paschim Bardhaman, WB – 713332
(M) 9434795113/8927440405
Email : sandipcil1975@gmail.com

Shri Sandip Kumar Saha (LM - 11162)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Flat 9B, Block 2, Natural Heights,
Durgapur – 713218, West Bengal
(M) 9434796619/8617568547
Email : sandipkumarsaha1971@gmail.com

Shri Anand Prakash (LM - 11163)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Qr. No. D/09, Gopalpura Colony,
MugmaEqrakund, Jharkhand – 828 204
(M) 9434796730/9775773598
Email : anand.prakash@coalindia.in
prakash.anand48@gmail.com

Shri Sidhdharth Haridas Wele (LM - 11164)
Dy. Manager (Mining), ECL
Eastern Coalfields Ltd
Q.No. 1/1, Near Durga Mandir, Shivdunga
Post : NinghaDist : Paschim Bardhaman
West Bengal – 713370, (M) 9434795620
Email : siddharthwele@yahoo.in

Ali Murtoja Shaikh (LM - 11165)
Dy. Manager, ECL
Eastern Coalfields Ltd
Vill : chuapukur, P.O. Sagia, P.S. Lalgola
Dist : Murshidabad, WB – 742151
(M) 9434796283/9735438242
Email : murtoja6696@gmail.com

Shri Snehanshu Roy (LM - 11166)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
D-1, Agents Bunglow At Post – Ningha
Dist - Paschim Burdwan – 713370
West Bengal, (M) 9434796599
Email : snehanshu01021965@gmail.com

Shri Swadhin Kumar Shitt (LM - 11167)
Sr. Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr.No. D-01, Kunustoria Area Complex,
P.O. Topsi, Dist : Paschim Bardhaman
West Bengal – 713362
(M) 9434796207/9801370603
Email : swadhin0802@gmail.com
sk.shitt@coalindia.in

Shri Sajib Chattopadhyay (LM - 11168)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr. No. C-03-011, Dhemomain Colliery
Asansol, Paschim Bardhaman – 713367
(M) 9434795862/6295434247

Email : agentbansra@gmail.com
schattopadhyay2013@rediffmail.com

Shri Manoj Kumar (LM - 11169)
Chief Manager (Mining)/Agent, ECL
Eastern Coalfields Ltd
Tower - 4, Flat No. 2/C, Genex Exotica, Asansol,
Dist : Paschim Bardwan
West Bengal – 713304
(M) 9434796662/9434577362
Email : mk01011970@gmail.com

Md. Samir Ansari (LM - 11170)
Manager, ECL
Eastern Coalfields Ltd
Jealgora Near BCCL Guest House
P.O. Jealgora, Dhanbad,
Jharkhand – 828110
(M) 9771444869/7033506183
Email : samiransari69@gmail.com

Shri Sabyasachi Roy (LM - 11171)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Block-A-15, Flat 6C, Sugam Park, KSTP,
South Dhadka, Asansol – 713302, WB
(M) 9434796720/9434334607
Email : sabyasachiroy66@gmail.com
sabyasachi.roy@coalindia.in

Shri Sukomal Das (LM - 11172)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
A-7/9, Naba Ananya Co.Op, Housing Society Ltd,
Vivekananda Sarani, P.O. Ramkrishna Mission,
Asansol, Paschim Bardwan – 713305, WB
(M) 9434796719/9851145627
Email : sukomal.das@coalindia.in
iamsukomal@gmail.com

Shri Purushottam Barnwal (LM - 11173)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr. No. D - 09, Urjanagar, P.O. Mahagama
Dist.Godda, Jharkhand – 814154
(M) 9771447265/9431385497
Email : pbarnwal1401@gmail.com
asurjml@gmail.com

Shri Dhananjay AnandraoRagit (LM - 11174)
Sr. Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr. No. D-15, New V N Colony, ECL
P.O. Bahadurpur,
Dist – Paschim Burdhman – 713362, WB
(M) 9434796480/9860013697
Email : daragit1@gmail.com
ampcdsbarea@gmail.com

Shri Upendra Singh (LM - 11175)
General Manager (Mining), ECL
Eastern Coalfields Ltd
GM's Office, Satgram-Sripur Area
P.O. Devchandnagar
Dist : Paschim Bardhaman– 713332, WB
(M) 9434793006/9431379359
Email : gm.satgram@gmail.com
usingh1234@gmail.com

Shri Sourav Agarwal (LM-11176)
Dy. Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr. No. B3/15, 3rd Floor, Kalidaspur
ECL Colony, P.O. Bharo Kalibari,
P.S. Mejhia, Dist – Bankura, WB-722143
(M) 9434796742 /9165336100
Email : sourav.agarwal@coalindia.in
souravagarwal.mining09@gmail.com

Shri Om Prakash Choubey (LM - 11177)
General Manager (Mining), ECL
Eastern Coalfields Ltd
D-03, Urjanagar, Mahagama, Godda,
Jharkhand – 814154, (M) 7488973046
Email : choubeysom@gmail.com

Shri Saurabh Sah (LM - 11178)
Dy. Manager (Mining), ECL
Eastern Coalfields Ltd
C-17/43, Urjanagar, Mahagama, Godda
Jharkhand – 814154, (M) 8210417362/7752957698

Email : sahsaurabh987@gmail.com
saurabh.sah@coalindia.in

Shri Ranjan Madhukar (LM - 11179)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr. No. DEQ/007, Bankola Area Colony,
Near Bankola Area Guest House
Ukhra, Paschim Bardhaman – 713363, WB
(M) 9434796318/7541884869
Email : mranjan13@yahoo.co.in

Shri Mrityunjay Kumar Singh (LM - 11180)
Sr. Officer (Mining), ECL
Eastern Coalfields Ltd
At - Haripur Officer Colony,
Qtr. No. B/8, P.O. Haripur,
Dist – West Bardhaman – 713378, WB
(M) 6371802567
Email : mksingham1979@gmail.com

Shri Satish Murari (LM - 11181)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Atr. No. D-21, Urjanagar Colony, P.O. Mahagama,
Dist – Godda, Jharkhand -814154
(M) 9046054357/9832251969
Email : satishmurari11@gmail.com

Shri Raj Kishore Singh (LM - 11182)
General Manager (Mining), ECL
Eastern Coalfields Ltd
D-1, Haripur Officer's Quarter Complex,
P.O. Haripur, P.S. Pandabeswar
Dist : Paschim Bardhaman – 713378, WB
(M) 9434796539/9800185316
Email : jmsrajthu.kishore@gmail.com

Shri Bhaskar Bhattacharyya (LM - 11183)
Chief Manager (Geology), ECL
Eastern Coalfields Ltd
Manasadham Appartment, B Block, 2nd Floor,
Hindusthan Park, Street No. 2, Asansol
West Bengal – 713304
(M) 7364874033/9434795255
Email : bhaskarcil66@gmail.com

Shri Amitava Bhattacharyya (LM - 11184)
General Manager (Mining), ECL
Eastern Coalfields Ltd
Golap Bagan Lane, Dabor More
P.O. Rupnarayanpur Bazar,
West Bardhaman – 713386
(M) 9434795878
Email : amitava.buku@gmail.com

Shri Indrajit Kumar Sharma (LM - 11185)
Sr. Manager (Mining), ECL
Eastern Coalfields Ltd
D-11, Urjanagar ECL Colony, Mahagama,
Dist – Godda, Jharkhand – 814154
(M) 9771447186/9131307426
Email : indrajeetsharma464@gmail.com
indrajeet.sharma@coalindia.in

Shri Sanjay Mandal (LM - 11186)
Dy. Manager (Mining), ECL
Eastern Coalfields Ltd
Room No. C-10, Haripur Officer Colony
SBP, P.O. Haripur,
Dist : West Burdwan – 713378, WB
(M) 9981222883
Email : sanjayiiest@gmail.com

Shri Manish Kumar (A - 11187)
Asstt. Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr No.CEQ-02/005, DPS More, Opposite SBI,
Chinakuri III, Asansol – 713360, WB
(M) 9434795225/8271297177
Email : manishkumar026@gmail.com
manish.kumar188@coalindia.in

Shri Ajit Kumar Singh (LM - 11188)
Sr. Manager ((Mining), ECL
Eastern Coalfields Ltd
DEQ001/001A, Near Kumardhubi Colliery Office,
Post. Chirkunda, Dist. Dhanbad
Jharkhand – 828202, (M) 9771444812
Email : ajitacm@gmail.com

Shri Chand Babu (LM - 11189)
Manager (Mining), ECL
Eastern Coalfields Ltd

Qtr. No. C-3/11, Gopalpura Colony, Mugma,
Dhanbad – 828204, Jharkhand
(M) 9771444875/9431720248
Email : chandbabu66@gmail.com
chandbabu@coalindia.in

Shri Dilip Roy (LM - 11190)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
D-5, Gopalpura Colony, P.O. Mugma
Dist: Dhanbad, Jharkhand – 828204
(M) 9771447267
Email : roydilip953@gmail.com

Shri Ramprawesh Kumar Singh (LM - 11191)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Qtr. No. KDC/DEQ/002/002, Kumardhubi Colliery, PO. Chirkunda, Dist: Dhanbad
Jharkhand – 828202, (M) 9434796698/6294586137
Email : krpchinakuri@gmail.com

Shri Lalit Kumar Mehta (LM - 11192)
Mine Manager, ECL
Eastern Coalfields Ltd
Qtr. No. C/02/06, Lakhimata Officer's Colony
Nirsa, Dist _ Dhanbad, Jharkhand – 828205
(M) 9771444909/9430187955
Email : lalitmehta1990@gmail.com
lalit.mehta@coalindia.in

Shri Praveen Kumar Mishra (LM - 11193)
Manager (Mining), ECL
Eastern Coalfields Ltd
C/01/004, Lakhimata Officer's Colony,
Behind Unique Family Restaurant, Nisra,
Dhanbad, Jharkhand – 828205
(M) 9771444878/8100529666
Email : praveenkr.iitkgp@gmail.com
praveen.mishra@coalindia.in

Shri Saral Sahu (LM - 11194)
Chief Manager, ECL
Eastern Coalfields Ltd
Qtr. No. C/4/20, Haripur Officer Colony,
P.O. Haripur, West Burdwan – 713378, WB
(M) 9434795776/9434590681
Email : saralsahu9@gmail.com

Shri Prasanta Sarkar (LM - 11195)
Manager, ECL
Eastern Coalfields Ltd
Narsamvda Colliery, C-01-01, P.O. Mithni,
Dist – Paschim Bardhaman – 713371, WB
(M) 9434796124
Email : prasantasarkar21.ps@gmail.com

Shri Ashis Kayal (LM - 11196)
Manager (Mining), ECL
Eastern Coalfields Ltd
Regional Hospiptal Chora, Qtr. No. C:01/02
P.O. Bahula, Dist : Paschim Bardhaman
West Bengal – 713322, (M) 9434795634
Email : bapi.rounak@gmail.com

Shri Rajiv Kumar Sinha (LM - 11197)
Chief Manager (Mining), ECL
Eastern Coalfields Ltd
Area Safety Officer, Kenda Area ECL
PO. Haripur, West Burdwan – 713378, WB
(M) 9434796919/9933577252
Email : rajivsinha116@gmail.com

Shri Arvind G (A-11198)
Asstt. Manager (Mining), ECL
Eastern Coalfields Ltd
C/01/003, New Satgram, Bogra, Asansol
West Bengal – 713332
(M) 9046138107/8667274405
Email : arrvind.g@coalindia.in

19TH FOUNDATION DAY LECTURE

The 19th Foundation Day Lecture of The Mining, Geological & Metallurgical Institute of India (MGMI) was delivered by Shri S. Suresh Kumar, IAS, Chairman, Damodar Valley Corporation at Dishergarh Club, Sanctoria, Eastern Coalfields Limited on 15th June 2024. The Guest of Honour at the event was Shri P.M. Prasad, Chairman Coal India Limited. Other guests on the dais were Dr B.V. Reddy, Dir (Tech), CIL & Honorary President, MGMI, Shri Ranajit Talapatra, Honorary Secretary, MGMI, Dr. C.S. Singh, Honorary Joint Secretary, MGMI, Shri Niladri Ray, Director (Tech), ECL, Shri Samiran Dutta, C & MD, ECL.

At the outset, Shri Kumar thanked MGMI for inviting him to deliver the 19th Foundation Day Lecture. His topic of discussions was 'Repurposing of Coal Mines for a Just Transition'. The Government of India has identified as many as 299 mines as abandoned, discontinued and closed. These mines are presently occupying large parcels of land that remain unused. By 2070, India's target to achieving net zero - India will require three times more energy than it did in 2019. Achieving the Renewable Energy (RE) targets will require acquisition of large tracts of land. Utilization of land associated with abandoned mines, for repurposing can support realization of RE targets and other commercially viable business models. With proper planning and investment, these lands can be repurposed for a variety of applications, such as renewable energy development, data centre development, agriculture, and recreation, among others. Repurposing of closed mines is also an enabler of "Just Transition", a concept which has been around since the 1980s. In recent years, the concept has gained traction with reference to meeting climate goals by ensuring the whole of society – all communities, all workers, all social groups – are brought along in the pivot to a net-zero future. Just transition is even more important since the coal sector is deeply interconnected, not only to other sectors, but also to the local communities. Coal in India occurs in states which are economically disadvantaged. If done right, the transition offers immense opportunities: systems change in which all communities, workers, and countries are lifted up.

Shri Kumar continued his deliberations on 'Repurposing Business Models' under a few subheads.

(i) **Underground Pump Storage System** -- In response to reducing carbon emissions, many countries are currently undergoing an energy transition to mitigate their environmental impact with a growing reliance on renewable energy sources like solar and wind power, which exhibit great variability. Consequently, to address the challenge of temporal matching between energy supply and demand, various energy storage technologies have emerged as potential solutions such as pumped-storage hydroelectricity (PSH) representing 99% of global storage capacity. Underground Pumped Storage Power Plants (UPSP), as first introduced in the early 20th century, offer a viable solution that capitalizes on the utilization of abandoned underground spaces and effectively circumvents topographical constraints and limita¬tions associated with surface footprint.

(ii) **Solar PV** -- Floating solar PV panels at flooded open pits are an option under active consideration. Former lignite open cast mines are also good locations for FPV since a connection to the grid already exists as a rule. If anchoring on land is not possible, then a conventional ship anchor can be used. However, this can lead to additional costs, which depend on the pit depth.

iii. **Gravitational Energy Using Mine Shafts --** Gravity-based energy storage devices involve the use of heavy weights that may be raised when there is surplus renewable energy generation, likely to be from solar or wind power. The weights are lowered in a shaft to generate power when there is a deficit. Potential energy is thus converted to electricity on demand. The concept is to adapt a disused mine shaft to raise and lower weights connected to an electric motor that also acts as a generator. An existing vertical shaft avoids the need to build a structure above or below ground.

(**iv) Hydrogen Storage in Mine Shaft Vessels --** There is international interest in the use of hydrogen (H_2) as a decarbonised fuel system; the significance of hydrogen is that it can be produced using renewable electricity that provides a unique form of chemical energy that can be used in a similar way to fossil fuels. Gravitricity is initially focused on the development of gravitational energy storage, but there is an alternative energy storage concept for hydrogen in mines. An attractive option may be to reuse coal mine shafts, inserting vessels where a lined shaft wall provides part of the containment system.

(v) Dumping of ash -- As it is well known, evacuation of ash from thermal power plants is a major problem. A larger number of abandoned mines should be made available to power producers for sustainable generation. Infact, it is proposed that Fuel Supply Agreements (FSAs) must include an assurance of allotment of abandoned mines by the supplying entity for dumping ash of a concomitant quantity considering ash content of the supplied Grade of Coal.

(vi) Geothermal Energy -- Another option for the use of old mine workings is to extract warm water present in them for use in nearby district heating schemes. The warm water is due to the geothermal gradient in the earth's crust, such that for each kilometre the temperature rises by about 25°C.

(vii) Batteries -- Batteries require little other infrastructure but do occupy a large area. The use of mines could mean substantial savings compared to conventional hydro projects requiring tunnelling.

(viii) Small Modular Reactors (SMRs) -- SMRs can be defined as nuclear reactors with a power output of up to and around 300 MWe that incorporate by design higher safety, modularisation, standardisation. Today, more than 70 concepts are under development covering a wide range of technology approaches and maturity levels. They are claimed to have great advantages in terms of safety through increased use of smart innovative technology and inherent safety features.

(ix) Nature Recovery -- There is also the opportunity to restore the landscape by establishing forests, wetlands and parkland. This is especially the case where sites are remote from population centres and where extensive shallow underground works pose risks of subsidence.

(x) Data Centres -- Data centers are the engines of the digital economy, and their development, powered by renewable energy, on former mine sites is a focus of this study. Mines offer reclaimed land and the electrical infrastructure to support data centre needs.

Then Shri Kumar discussed benefits of repurposing, concluding the breadth of options for repurposing former coal sites is truly extensive. Many of these projects are just coming off the drawing board.


THE MINING, GEOLOGICAL AND METALLURGICAL INSTITUTE OF INDIA
19th Foundation Day Lecture
By
Shri S Suresh Kumar, IAS
(Chairman, Damodar Valley Corporation)
Guest of Honour: Shri P M Prasad

IMPORTANCE OF CRITICAL MINERALS IN INDIA

A Conversation with Shri Janardan Prasad, Director General, Geological Survey of India

Shri Janardan Prasad presently holding the position of Director General of Geological Survey of India started his professional journey at the Central Ground Water Board in Nagpur, where he made significant contributions to groundwater exploration in Maharashtra. His illustrious career began after completing his post-graduation from Patna University. After joining the Geological Survey of India in 1986, he dedicated over three decades to mineral exploration, geoscientific data collection, and petrological research across India. His leadership roles have spanned several regions, culminating in his current position as Director General, which he assumed in May 2023. Shri Prasad's expertise and dedication to the field made him an invaluable asset to India's geoscientific community. Our Guest Editor, Dr. Ajoy Kumar Moitra had the privilege of speaking with Shri Prasad. This interview is presented to our readers, offering valuable insights and perspectives from one of India's leading geoscientists for their benefit and understanding.

Could you kindly provide us with a brief overview of your professional journey and experiences throughout your tenure at the Geological Survey of India?

After completing my post-graduation at Patna University, I commenced my professional journey by joining Central Ground Water Board, Central Region Nagpur where I did Ground water exploration in Tapi alluvium in Jalgao and Bhushawal districts and Chandrapur district, Maharashtra (December1986 to 1988). After selection of UPSC (1986) I joined GSI Western Region, Gandhinagar on 27.12.1988. I served there for 23 years, followed by my postings across Northeastern Region, Eastern Region, Northern Region, and Southern Region. During this time, I have worked extensively on projects ranging from mineral exploration, baseline geoscientific data collection and petrological research across various terrains of India.

In 2013, I was nominated as member in the prestigious Hon'ble Justice M. B. Shah Commission for inquiry of Illegal Mining of Iron and Manganese in the States of Andhra Pradesh, Goa, Jharkhand, Karnataka, Chhattisgarh and Odisha, where the central and state governments were incurring a huge loss of revenue. During my tenure in Hon'ble Justice M. B. Shah Commission, the Hon'ble Supreme Court passed a very important verdict which led to the recovery of crores of money in terms of revenue from illegal mining.

In 2020, I assumed the role of Additional Director General & Head of Department at the Geological Survey of India, Southern Region. Additionally, I served as the Chairman of the Technical-cum-

Cost Committee (TCC) for the National Mineral Exploration Trust (NMET) from 2020 to 2023, where I reviewed numerous Pan-India projects submitted by various exploration agencies, contributing to the advancement of mineral exploration endeavors nationwide.

Ministry of Mines nominated me as a member of the Indian delegation led by Additional Secretary, MoM to Geneva, Switzerland for participation in the 18th Annual General Meeting of the Inter-Governmental Forum during 7-10 November, 2022.

What are the key objectives and role of the Geological Survey of India (GSI) in the context of exploring India's critical mineral wealth?

The primary objective of GSI is to provide unbiased and accurate geological knowledge and geoscientific data for the nation. We play a crucial role in mineral resource assessment through ground, airborne, and marine surveys, covering both conventional and critical minerals. Our priority lies in furnishing this information to support policymaking and fulfill the commercial and socio-economic needs of our stakeholders.

The Government of India has implemented various policy reforms aimed at enhancing mineral production and strengthening the country's self-reliance. GSI plays a crucial role in this endeavor by identifying and providing critical and strategic mineral blocks/areas to the Central Government for auctioning as composite licenses and mining leases. In line with these objectives, GSI has ramped up its exploration efforts for critical minerals through its field season programs. This is aimed at supporting India's journey towards achieving self-reliance (Atmanirbhar Bharat) in critical mineral production by 2047.

In the quest for critical minerals GSI has completed National Geochemical Mapping in 21.39 lakh sq. km. area and National Geophysical Mapping has been completed in 14.05 lakh sq. km. area till date, both these achievements cover the entire Obvious Geological Potential area (OGP). Specialized Thematic Mapping has been completed in 4.22 lakh sq. km and Sea Bed Mapping as already been done in 20.54 lakh sq.km (88.99%) of the EEZ of India. National Aero Geophysical Mapping has been completed in 4.29 lakh Sq. Km. area.

Could you kindly provide a summary of the current state of critical mineral exploration initiatives in India, specifically focusing on those led by the Geological Survey of India (GSI)?

The Mines and Minerals (Development and Regulation) Act, 1957 has been amended by the Mines and Minerals (Development and Regulation) Amendment Act, 2023 with effect from 17.08.2023 by Central Government. The Amendment Act, inter alia, inserted section 11D in the Act which empowers the Central Government to exclusively auction mining leases and composite licenses in respect of 'critical and strategic mineral' specified in Part D of the First Schedule of the Act. This empowered the Ministry of Mines to auction Critical and Strategic Mineral blocks on behalf of the Central Government. Geological Survey of India is the major contributor in identification of critical mineral blocks put up for auction by Central Government. GSI is constantly working on feasible areas for exploring critical minerals throughout the country. GSI is constantly enhancing its technological capabilities to achieve the nations target of achieving carbon neutrality.

Recently, the Government of India introduced new mineral concession of exploration licenses (EL) to be granted for exploration of critical minerals and to encourage private participation for exploration of critical minerals. GSI has been instrumental in identifying and developing exploration blocks, subsequently handing them over to the respective states for auction.

GSI serves as the nodal agency for implementing the National Geoscience Data Repository (NGDR). NGDR aims to empower stakeholders of various industries and academia by providing them with unparalleled access to priceless geospatial assets. Its goal is to compile and distribute all valuable legacy geoscientific data related to exploration for the benefit of stakeholders. This repository will also help in targeting EL and CL blocks.

What are some of the most promising regions in India for critical mineral exploration, and what factors contribute to their potential?

India is endowed with rich and varied geological setup, offering substantial potential for critical mineral resources. The North Eastern Region, particularly Arunachal Pradesh, holds promise for graphite and vanadium, owing to favourable host rocks such as carbonaceous phyllite. Rajasthan stands out for lithium due to enriched pegmatite formations, while Karnataka and Gujarat are recognized for Rare Earth Elements (REE) found in carbonatite deposits. Coastal regions like Kerala and Andhra Pradesh present opportunities for REE extraction from beach sands. These represent a few focus areas among many others. We are also giving emphasis on searching Lithium in mica belts of India as primary ore besides secondary mineralisation.

Do you not think some more minerals are required to be enlisted as Critical Minerals?

In June 2023, the Union Minister of Coal, Mines & Parliamentary Affairs, Shri Pralhad Joshi, unveiled the nation's first report on "Critical Minerals for India," identifying 30 essential minerals with 24 of them included in the list of critical and strategic minerals under the Part D of Schedule 1 of MMDR Act. These minerals are vital for industries such as defence, agriculture, energy, pharmaceuticals, telecommunications, and are also crucial for achieving India's 'Net Zero' target. The criteria for listing critical minerals depends on policy, availability of mineral in the country, technology, high tech utility, etc. As the formalities for the auction process for these minerals are nearing completion, it will be interesting to observe how these policies unfold.

How does the GSI prioritize its exploration efforts among different critical minerals, considering both domestic demand and global market trends?

Present Exploration activities in India are prioritized and focused as per guidelines of Ministry of Mines, Government of India through amendment of MMDR Act of 1957 in 2015, 2021, 2023; NMEP-2016, NMP-2019, CGPB, SGPB, NMET and various reform policies. Accordingly, GSI has also prioritized its > 35 % annual field season programs dedicated to critical mineral exploration.

What are the main challenges and obstacles faced by the GSI in its exploration endeavours for critical minerals?

The main challenges include declining ore grades, optimization of beneficiation techniques, challenges related to obtaining forest permissions for exploration activities as well as local issues and public resistance.

How does the GSI collaborate with other government agencies, private sector entities, and international partners to accelerate critical mineral exploration efforts?

The Geological Survey of India (GSI) has been actively engaged in organizing several seminars and symposiums involving our stake holders, both from government and private sectors. GSI also undertakes knowledge exchange programs through bilateral and multilateral talks with countries like Brazil, Japan, Australia, and the United States. These collaborations foster valuable insights and promote scientific cooperation in the field of geology.

Can you elaborate on any recent technological advancements or innovative approaches employed by the GSI to improve the efficiency and accuracy of mineral exploration? For example, recently developed softwares, drone mapping and could be even artificial intelligence?

GSI is adopting innovative strategies to enhance the efficiency and precision of mineral exploration through the integration of Artificial Intelligence

(AI) and Machine Learning (ML). Additionally, the establishment of a regional geoscience data division for implementing AI-ML pilot programs in mineral exploration is a commendable step. With the implementation of the NGDR portal, data accessibility and sharing in GIS format will streamline access and expedite decision-making processes.

In what ways does the GSI ensure environmentally sustainable practices in its exploration activities, particularly in ecologically sensitive areas?

GSI follows all guidelines issued by the Ministry of Environment, Forest and Climate Change, Government of India and ensures that its exploration activities are sustainable to environment.

How does the GSI assess the economic viability of potential mineral deposits and their potential contribution to India's industrial and economic growth?

The Geological Survey of India (GSI) adopts a systematic and scientific approach in its exploration endeavours, aligning with the United Nations Framework Classification (UNFC) for Resources as per The Minerals (Evidence of Mineral Contents) (MEMC) Rules, 2015. Following drilling activities, GSI employs specific resource calculation methods depending on the nature of the deposit to evaluate the mineral potential. Factors such as the mode of occurrence of the target metal and the available technology play a crucial role in determining the economic viability of the deposit.

To enumerate status of exploration in an area which classification you are following. Presumably it is UNFC classifications being followed. Your version please.

GSI has been following the UNFC classification of mineral coding. This standardized approach ensures consistency and facilitates effective communication across the global geoscience community.

What measures does the GSI take to promote responsible mining practices and mitigate the negative environmental and social impacts associated with mineral extraction?

GSI is responsible for the systematic geological survey of the country and its exclusive economic zone, along with the exploration and evaluation of mineral resources.It is important to note that GSI is not engaged in mining activities.

How does the GSI engage with local communities and indigenous peoples in areas where mineral exploration activities are being conducted?

GSI conducts exploration in remote areas, actively engaging local communities and indigenous peoples during the mineral exploration activities from G4 to G2 stage. GSI officers frequently visit schools and colleges in these areas as part of its flagship program, Bhuvisamvad, to engage with students and enhance their understanding of geology and potential career opportunities in the field. Additionally, local individuals are employed as daily laborers and compensated according to government regulations.

Could you share any success stories or notable achievements of the GSI in discovering and developing critical mineral resources in India?

Case study from Gundlupet REE deposits, Karnataka depicting stages of project development seamlessly from STM to G2 stage.

- During STM (FS-2020-21), Carbonatite and syenite were reported for the first time as intrusive rocks in the PGC. The strike extension of carbonatite was mapped up to 1.5 km. The ΣREE content in carbonatite ranged from 3437.6 ppm to 10151.2 ppm, with an average of 7371 ppm. The carbonatite is enriched in LREE with values ranging between 3272.5 ppm to 9945.9 ppm with an average of 7178.9 ppm.
- During G4 (FS-2021-22), Geological and geophysical mapping helped to demarcate 6 carbonatite bodies having variable width and the strike extension was proved upto 1.7 km. 3

scout boreholes (469.50 m) were drilled and subsurface extension was proved upto 100m vertical depth. The REO resources estimated is 5.37 million tonnes at 0.1% REO cut-off with an average grade of 4526 ppm of TREO.

- G3 (FS-2022-23)10 boreholes were drilled totaling 1415.65m, of which 9 boreholes intersected the REE zones. The strike of the carbonatite was extended upto 2.4 km length based on subsurface exploration. The tentative REO resources estimated is 6.94 million tonnes at 0.1% REO cut-off with an average grade of 4031 ppm of TREO (RE_2O_3) (from 5 boreholes).
- G2 (FS-2023-24) : Total 4500m drilling has been planned which comprises 16 first level boreholes, 10 second level boreholes and 1 third level borehole. Four boreholes have been completed till date and all of them have intersected the REE zones and strike extension was proved upto 2.5 km length.

What are the GSI's long-term goals and strategies for ensuring sustainable and equitable utilization of India's critical mineral wealth?

GSI will continue its exploration activities as per the policy demands of Government of India. Over the long term, it aims to target unconventional areas for exploration. A focused approach will be adopted, particularly in quaternary deposits, to search for critical minerals in both the Himalayan and peninsular regions of India. Additionally, exploration efforts will be directed towards regolith, riverine deposits, coastal belts, and the exclusive economic zones of India.

How does the GSI contribute to policy formulation and decision-making processes related to mineral resource management and development in India?

The Geological Survey of India (GSI) significantly influences policy formulation and decision-making processes regarding mineral resource management and development in India. Through its data-driven insights, GSI provides policymakers with comprehensive geoscientific data, facilitating effective strategies for mineral management. Additionally, GSI experts actively contribute their technical expertise to committees, working groups, and policy discussions, guiding decisions on exploration, extraction, and sustainable utilization. By aligning its long-term vision with national goals, such as self-reliance and resource security, GSI plays a crucial role in shaping policies that promote responsible mineral exploration in India.

What advice would you offer to young professionals aspiring to pursue careers in the field of geological exploration and mineral resource management?

India with a land mass of about 3.2 million sq. km and Exclusive Economic Zone of about 2.3 million sq. km with immense geological potential. It has a vibrant mining and exploration ecosystem, produces 95 minerals including major, minor, 24 critical, 4 energy, and 12 atomic minerals.

Mineral exploration in India has a glorious past dating back to the Iron and Bronze ages, and it holds great promise for the future, particularly for young professionals aspiring to pursue careers in this field. The integration of technologies, such as Artificial Intelligence (AI), Machine Learning (ML), Information Technology (IT), and data science, has opened up exciting new avenues for innovation and advancement in mineral exploration and mining. A career in geological exploration offers both rewards and challenges, encouraging individuals to unravel Earth's mysteries while contributing to sustainable development.

Shri Janardan Prasad, Director General, Geological Survey of India in his interview with Dr. Ajoy Kumar Moitra, Guest Editor of this special issue

PERSPECTIVE PIECE

CRITICAL MINERALS IN THE MODERN ECONOMY : TECHNOLOGICAL INNOVATIONS AND GLOBAL TRENDS

Aranya Bhaduri*

Abstract

The importance of critical minerals in the modern economy cannot be overstated. Critical minerals are fundamental to several key areas, such as sustainable energy solutions, high-tech industries, aerospace and defence. The increasing global population, industrialisation, digitisation, increasing demand from developing economies, and the criticality of addressing climate change are leading to increasing pressure on these resources. This paper reviews the role of critical minerals in building our present, focusing on the current market trends and some of the technological innovations that are facilitating our journey towards a more sustainable future.

Security of critical mineral resources has been strongly linked to sustainable development objectives including economic, environmental and societal development. Adequate and reliable supply chain for rapidly growing technologies such as solar photo voltaics (PV), Li-ion batteries, wind turbines and elements of digitisation are vital issues faced by countries. The growing import dependency and strategic importance of critical minerals along with the need for addressing the market dynamics, and economic challenges has led industries, researchers and governments worldwide to find ways to optimise their primary extraction and processing methodologies in addition to engaging in dialogues with resource-rich countries. Several technological developments in extracting critical minerals, such as hydrometallurgy, bioleaching and in-situ leaching, have improved their efficiency, enabling minimisation of environmental impact compared to traditional mining methods. Improvements in processing techniques such as electrochemical processing, ion exchange and membrane technologies are offering innovative solutions to the crucial aspect of separating and purifying these minerals, contributing to the overall sustainability of the process and improving the economic impact. Cost-benefit analyses have indicated that these advances lower production costs while enhancing resource recovery rates, influencing market dynamics by stabilising supply chains and price volatility.

Higher accessibility and affordability of resources are linked with better stability in market prices, facilitating investment in projects reliant on these resources and, in turn, fostering economic growth and technological progress. Government policies, international cooperation and private-sector investments are critical in encouraging innovation. Regulatory support is vital to reducing the financial risk of developing new extraction and processing technologies. Private sector investments drive collaboration between industry and academia, encouraging innovation by funding research and development and accelerating the commercialisation of new technologies.

This review paper discusses some of the critical considerations and challenges relevant to the role of critical minerals in shaping our current and future world.

Key words : *Critical minerals, criticality, hydrometallurgy, bioleaching, in-situ leaching, electrochemical processing, ion exchange, sustainability, supply chain*

* ISMAA Kolklata Chapter, Pursuing Masters in Energy and Environmental Technology and Economics at School of Science and Technology, University of London
aranyabhaduri@gmail.com

Introduction

What are "critical minerals"?

The term "critical minerals" is an umbrella term encompassing a broad range of raw materials that do not have any viable substitutes with present technologies and which most consumer countries depend on importing (Overland, 2019). Creating a single all-embracing definition or list is challenging, as industries, governments and organisations each assess the 'criticality' of these minerals from different perspectives (kirsty critical mineral, 2021). Factors affecting criticality include industrial necessity, minerals with defence importance, limitations of domestically available resources, geological scarcity and geopolitical instability, posing a threat to the supply chain (Hayes and Mc Cullough, 2018). The following sections discuss some of these factors from the viewpoints of the European Union, United States of America, United Kingdom and India.

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Critical mineral lists and assessment approach

Economic development, rapid technological innovations, and the need to meet sustainability goals have resulted in severe demand pressures for critical minerals. Considering rising prices and production delays, the vulnerability of supply chains has become a crucial focus. As per IEA, the major factors adding to the risks of stability and reliability of supply chains include the following. (Leruth *et al., 2022)*

1. Production and processing are concentrated primarily in a small number of countries.
2. The continual deterioration of ore quality increases extraction costs and creates pollution risks.
3. Climate risks at the production sites

4. Environmental, social and governance (ESG) considerations
5. Derived demand due to inter dependency between new technology and infrastructure

Different countries or groups of countries assess critical mineral resources based on factors and methodologies most relevant to their specific case within the global dynamics.

European Union

Safeguarding adequate supplies of raw materials critical to strategic value chains has been identified as a major economic challenge for the EU. The advancing digital revolution, new innovations, e-mobility, artificial intelligence technologies, and the global shift towards sustainable energy are fuelling this rising demand. (Lewicka, Guzik and Galos, 2021). The European Union (EU) define their list based on their aspects of criticality. Following the EU Raw Materials Initiative (RMI) (single-market-economy.ec.europa.eu, 2008) the fifth technical assessment of critical materials was done. The methodology to assess criticality was centered around two main criteria -economic importance and supply risk. The proposal of the CRM Act Regulation included lists of Strategic Raw Materials (SRM) and CRM. (Directorate-General for Internal Market, Grohol and Veeh, 2023).

Table 1 below shows the EU critical mineral list.

Table 1 : EU CRM 2023 list

Aluminium/Bauxite	Coking coal	Lithium	Phosphorus
Antimony	Feldspar	5 Light Rare Earth (LREE)	Scandium
Arsenic	Fluorspar	Magnesium	Silicon Metal
Baryte	Gallium	Manganese	Strontium
Beryllium	Germanium	Natural Graphite	Tantaum
Bismuth	Hafnium	Niobium	Titanium Metal
Boron/Borate	Helium	5 Platinum Group metals (PGM)	Tungsten
Cobalt	10 Heavy Rare Earth (HREE)	Phophate rock	Vanadium
		copper*	nickel*

Copper and nickel are included as Strategic Raw Materials but do not meet the CRM thresholds.

United States of America

In USA, the Energy Act of 2020 describes a critical mineral as “a non-fuel mineral or mineral material essential to the economic or national security of the US and which has a supply chain vulnerable to disruption”. As per the Energy Act of 2020 requirement, the United States Geological Survey (USGS) issued a list of 50 mineral commodities after an extensive multi-agency assessment, given below in Table 2 (Burton, 2022). As per the directives of the Energy Act of 2020, the list and the methodology used to identify them are not static and must be reviewed and updated every three years. The methodology for developing the 2022 list was based on the criteria specified in the Energy Act and included metrics such as evaluation of supply risks and accessibility from foreign countries.

Table 2 : 2022 USGS list of critical minerals

Aluminum	Fluorspar	Manganese	Tellurium
Antimony	Gadolinium	Neodymium	Terbium
Arsenic	Gallium	Nickel	Thulium
Barite	Germanium	Niobium	Tin
Beryllium	Graphite	Palladium	Titanium
Bismuth	Hafnium	Platinum	Tungsten
Cerium	Holmium	Praseodymium	Vanadium
Cesium	Indium	Rhodium	Ytterbium
Chromium	Iridium	Rubidium	Yttrium
Cobalt	Lanthanum	Ruthenium	Zinc
Dysprosium	Lithium	Samarium	Zirconium
Erbium	Lutetium	Scandium	
Europium	Magnesium	Tantalum	

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United Kingdom

United Kingdom's Critical Mineral Strategy in 2023 has set out plans to secure supply chains by growing domestic capabilities, collaborating with international partners and enhancing international markets. The strategy involves maximising domestic production through rebuilding skills in mining in the country, promoting cutting-edge R&D, encouraging circular economy that improves recovery, reuse and recycling, collaborating with international partners and boosting international markets for higher transparency and responsiveness. Recognising the long-term nature of the strategy, the UK evaluates the criticality of minerals annually as part of the new Critical Minerals Intelligence Centre (CMIC), led by the British Geological Survey (BGS). The assessment methodology is evidence-based and is agreed upon by the Department for Business, Energy and Industrial Strategy (BEIS).

UK's critical mineral list includes the following (Table 3) :

Table 3 : UK critical mineral list

Antimony	Gallium	Lithium	Palladium	Silicon	Tin
Bismuth	Graphite	Magnesium	Platinum	Tantalum	Tungsten
Cobalt	Indium	Niobium	Rare Earth Elements	Tellurium	Vanadium

India

In India, the Ministry of Mines has been working on identification of minerals critical to India along with the Ministry of Power (Central Electricity Authority), Department of Atomic Energy (DAE), Ministry of New and Renewable Energy (MNRE), Ministry of Chemicals & Fertilizers (Department of Fertilizers), Ministry of Electronics & Information Technology (MEiTY), IREL (India), NITI Aayog among others, drawing learning from other agencies like the International Energy Agency (IEA) and CSEP who have adopted the EU methodology for evaluation of criticality of minerals. Based on a three-stage assessment process, the following 30 minerals were identified, considering parameters such as import dependency, resource/reserve position, use for future/clean energy technology, and fertiliser minerals. (Ministry of Mines June 2023 Report of the Committee on Identification of Critical Minerals).

Table 4 : India's critical mineral list

Antimony	Gallium	Lithium	Phosphorous	Strontium	Tungsten
Beryllium	Germanium	Molybdenum	Potash	Tantalum	Vanadium
Bismuth	Graphite	Niobium	REE	Tellurium	Zirconium
Cobalt	Hafnium	Nickel	Rhenium	Tin	Selenium and Cadmium
Copper	Indium	PGE	Silicon	Titanium	

Out of the above, 100% of lithium, cobalt, nickel, vanadium, niobium, germanium, rhenium, beryllium, tantalum and strontium were imported by India in 2020.

Minerals and their applications

Different technologies and usages need varying types of mineral resources. For example, battery technologies require lithium, nickel, cobalt and manganese. Permanent magnets used in wind turbines and electric vehicle motors need rare earth elements. Copper and aluminium are the foundation of electrical networks and electricity-based technologies. Compared to the 2010s, when the energy sector represented a minor part of the total demand, the current drive towards cleaner energy and electrification is leading to a considerable increase in demand for these minerals by the energy sector. As per IEA, EVs and battery storage have already become the largest consumer of lithium, surpassing consumer electronics. They are projected to surpass stainless steel as the end user of nickel by 2040. (IEA, 2021).

Photo by Mike Bird: https://www.pexels.com/photo/white-and-orange-gasoline-nozzle-110844/

As the demand for greener technologies rises, the availability of critical minerals becomes a significant aspect of the viability of the forward projections of the energy transition. In addition, the race to secure reliable supply is bringing the crucial element of ESG credentials of raw materials into increasing worldwide focus.

Technological innovations in mining and extraction

The mining of critical minerals is an evolving area that is adjusting to the rapid technological advances and the latest demand forecasts that affect the criticality of minerals. As per (ERM, 2023), the IEA's 'net zero emissions by 2050 scenario' requires the critical mineral supply to grow by three and half times by 2030 to meet the demands. However, developing new critical mineral mining projects can take up to two decades and could be exposed to delays from a few months to several years. Causes of delays could include technical challenges, permitting issues, environmental concerns and other commercial issues. Many critical materials are not economically viable to be extracted on their own and are extracted as by-products of mining and refining of primary and co-products such as copper, nickel, zinc and molybdenum. This also adds to uncertainties in accurately quantifying global resource estimates (McNulty and Jowitt, 2021).

Declining raw material quality, fine dissemination of valuable components, demanding mining conditions and exhaustibility of the raw material base for challenges in the global critical mineral sector. This is creating a demand for advanced mineral processing and exploring non-traditional sources of valuable components, such as black shales and refractory sulphide carbon-bearing ores. Addressing these challenges requires an integrated approach that employs activation and destruction methods at successive stages of mineral transformation, including comminution, beneficiation, and processing (*Aleksandrova et al., 2023)*. Technological innovation plays a big role in stabilising the supply of critical minerals, including mining, smelting and recovery of secondary resources. Advancements in extracting and processing critical minerals have improved their efficiency and sustainability (Song et al., 2022).

Primary minerals are typically extracted from ores collected from hard rock mines, but recent developments in mineral extraction technologies and declining ore grades in primary deposits have led to reprocessing mine tailings as a potential secondary source of critical minerals. Mine tailings, which are mixtures of fine-grained solid materials and water remaining after metal extraction, offer two key benefits for critical mineral extraction : reduced mining costs and a higher prospect of finding valuable minerals at economic concentrations, especially in older tailings due to less efficient past technologies. Many critical minerals, now vital for high-tech industries, were historically overlooked as byproducts during ore processing. With the growing demand for these minerals and fewer new discoveries of economically worthwhile deposits, recovering critical minerals from old mine tailings is gaining increasing attention, frequently finding concentrations that surpass even the primary ores *(Sarker et al., 2022)*.

Innovations such as hydrometallurgy, bioleaching, and in-situ leaching are providing cost-effective and less environmentally risky alternatives to traditional mining methods.

Hydrometallurgy uses aqueous chemistry for metal recovery from ores, concentrates, and recycled materials. It is also noted for its ability to process low-grade ores and reduce energy consumption (Encyclopedia Britannica, n.d.). It is especially effective in recovering precious metals from sulfide minerals and is increasingly vital for low-grade ores that are not profitable through conventional beneficiation methods. This extractive metallurgy technology is set to play an important role in the future of metal recovery. The processes used are leaching, solution concentration and purification, precipitation, cementation, electrowinning, solvent extraction, ion exchange and metal recovery involving electrolysis and precipitation. Hydrometallurgy, a relatively more environmentally friendly approach, can extract over 70 metallic elements and can extract low-grade ores (Sharma, 2023). Hydrometallurgy has been effectively used to produce Rare Earth Elements (REE). After producing a REE-containing concentrate through ore beneficiation, the following steps are dissolution, separation, and purification of rare earth elements, primarily using hydrometallurgy. These processes, well-established for minerals like monazite, involve dissolving REEs in acid under high pressure and temperature, separating them into pure solutions via solvent extraction or ion exchange, and generating individual, pure rare earth elements.

Optimising these techniques for other essential minerals remains necessary. Effective metal recovery requires a unique combination of these unit operations to ensure efficiency and purity (www.eurare.org, 2022). However, the use of large amounts of water can be a challenge in hydrometallurgy.

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Bioleaching employs microorganisms to extract metals from ores, offering a sustainable, cost-effective and environmentally sustainable technology for extracting metals from various minerals and waste materials. This method presents numerous advantages over conventional methods such as pyrometallurgy, which typically involve high energy consumption and extensive use of chemicals. By mitigating these negative impacts, bioleaching offers a more viable and eco-friendly alternative for metal extraction (Pathak, Morrison and Healy, 2017). Rare earth elements (REEs), essential for cutting-edge manufacturing areas such as renewable energy and electric vehicles, are increasingly recovered from low-grade resources like mining waste, where yttrium, cerium, and neodymium are commonly found in concentrations ranging from 50 to 300 μg/L. Biomining, particularly bioleaching, has emerged as a promising technique for REE recovery due to its reduced environmental impact, lower capital investment, high extraction efficiency (more than 80%), and high selectivity for REEs. However, bioleaching is time-consuming, taking months to years to complete *(Vo et al., 2024)*. The process requires specific environmental conditions due to microbial vulnerability and regular monitoring and maintenance for optimal microbial activity and efficiency *(Borja et al., 2016).*

In-situ leaching -Increasing costs in the mining industry have driven the need for alternative metal recovery methods for deposits that are no longer economically or environmentally feasible using conventional techniques. One such alternative method, in-situ mining, which is applied directly to the ore body without physical extraction, is an efficient and less disruptive method for mineral recovery. (Bahamòndez, 2016)

In situ recovery employs fluids to extract valuable minerals from underground deposits without extensive excavation in traditional open-cut or underground mining methods. Instead of physically removing the earth, this process involves injecting a lixiviant solution underground to mobilise minerals from the geological formations hosting them. After leaching, the solution, containing water and chemicals, is brought to the surface for mineral recovery and sale, with the remaining solution cycled back underground to extract additional minerals. This cycle continues until extraction is no longer economically feasible, after which the site undergoes rehabilitation and closure. The approach is best suited in cases where fluids can move effectively through the geology that hosts the minerals, the minerals are easily mobilised into solution and can be recovered later, and the process can be done economically and in an environment-friendly manner (Energy and Mining, 2022; (Visual Capitalist, 2019)

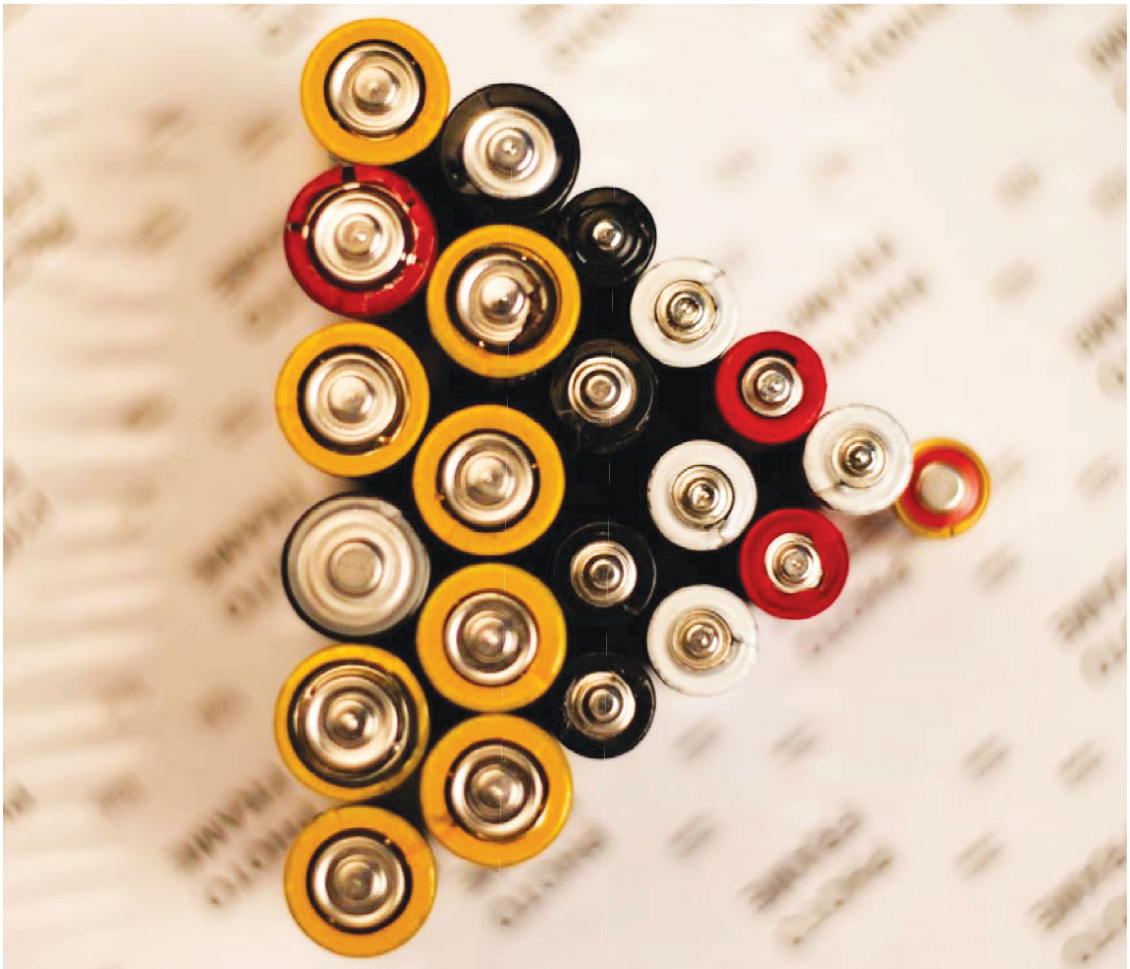
Market trends

Fuelled by high demand and rising prices, the market size for energy transition minerals has doubled in 2022, reaching USD 320 billion compared to 2017. With increased prospects of demand growth induced by energy transition, the investment in global critical minerals increased by 30% in 2022, followed by a 20% increase in 2021 with a growing exploration trend in Australia and Canada. The rare earth production, processing and consumption are very uneven worldwide. Global resource production of many critical minerals is more concentrated than hydrocarbon resources. For example, the world's top three producing countries of lithium, cobalt, and REE's controlled over three-quarters of global output in 2019. The Democratic Republic of the Congo (DRC) and the People's Republic of China produced about 70% and 60% of the global cobalt and REE's share in the same year. In 2023 China, USA, Myanmar, Australia, Thailand, India, Russia, Madagascar, Vietnam and Brazil were the leading producers of rare earths worldwide. China was the world's largest producer of REE by a considerable margin, followed by USA, with a production of about one-fifth of the output of China (Statista, 2024).

The processing operations are also very concentrated within some countries globally. For example, China's share of global refining operations in 2020 was about 35% for nickel, 50-70% for lithium and cobalt and about 90% for REEs (IEA, 2022).

Countries are trying to diversify by introducing new policies, and there is a growing recognition that policy intervention is vital to facilitating requisite and sustainable mineral supplies. The IEA policy tracker has found that over 100 policies have been enacted in just the past few years out of about two hundred policies and regulations from twentyfive countries and regions worldwide, such as the EU Critical Raw Materials (CRM) Act, Australia's Critical Minerals Strategy, Canada's Critical Minerals Strategy and the United States' Inflation Reduction Act among others (IEA, 2003). These have implications for trade and investment, including import or export restrictions. Globally, there has been about a fivefold increase of export restrictions since 2009, such as those in Indonesia, Zimbabwe and Namibia who have commenced ban on the export of unprocessed ores.

In addition to the supply side, innovation on the demand side also plays a massive role in building critical mineral resilience for the world. This includes improving the efficiency of mineral use by decreasing material intensity when developing green technologies, improving the design to promote greater recovery and recyclability, improving existing recycling technologies and innovations for switching to alternative, more abundant minerals (Le Menestrel, 2024).



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Summary

The demand from the energy sector has been one of the main contributing factors for a three fold increase in demand for lithium, a 70% rise in demand for cobalt and a 40% rise in demand for nickel. The sale of electric cars increased by 60% in 2022, surpassing 10 million units, energy storage system capacity doubled in 2022, and the renewable sector saw a solid upward trend. Due to the increasing demand, the critical minerals market has doubled in the past five years, taking centre stage in the mining and metals industry. This is witnessing a robust increase in these minerals worldwide. As per IEA, the demand for critical minerals is projected to grow by three and half times by 2030, reaching over 30 million tonnes in the Net Zero Emissions by 2050 (NZE) Scenario. Recent events such as export curbs on Chinese gallium and germanium in July 2023 have brought to attention the significance of lesser-known critical minerals such as magnesium, high-purity phosphorus and silicon and potential supply chain disruption from reliance on a small group of suppliers (IEA, 2023). Despite anticipated growth in demand, the supply of critical minerals is lagging, resulting in a persistent demand-supply gap.

Technological uncertainties, supply chain vulnerabilities due to market concentration, geopolitical tensions, and fluctuating prices discourage new investments from private and public sectors in critical minerals. The increasing demand also offers significant opportunities for developing countries rich in mineral resources to attract investment, create jobs, and enhance export and economic growth. (United Nations, 2024). A significant increase in mining exploration and refining patents and scientific publications over the past two decades show that technological innovations worldwide, especially in countries such as Australia, Canada, Europe and the USA supported by R&D investments, are playing a huge role in overcoming the challenges some of which are discussed in the paper. As per the United Nations (2024), securing international investments is critical for resource-risk economies such as India, Brazil, Indonesia, South Africa and Chile in enhancing their expertise and technological capabilities in the critical minerals industry, bolstered by their political and macroeconomic stability and robust ESG and legal frameworks. Regional initiatives and international collaboration are vital to promote technological innovation, social responsibility, improving market access and environmental sustainability.

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CRITICAL MINERAL SEARCH IN INDIA : A NEED FOR CHANGE IN APPROACH

Santanu Bhattacharjee

Economic importance and supply risks are the key factors which evaluate criticality of a mineral, other factors include recycling potential and substitutability. Recently Ministry of Mines has listed a group of 30 elements as critical which includes the rare earths, rare metals, battery minerals, fertiliser minerals etc, which are essential to our country's economic security, its supply is threatened and are required for our national transition to a low-carbon economy. These are vital to the space industry, electronics, information technology and communications, the energy sector, electric batteries, the nuclear industry etc. These sectors significantly depend on various critical minerals. Geological Survey of India has carried out systematic geological mapping (50 k) in 3.123 out of 3.146 million sq km, rest being inaccessible and has brought out potential areas for mineral exploration. Various projects are launched in this potential area viz., Regional Mineral Targeting project integrating geology and geophysics, National Aero geophysical mapping project involving aeromagnetic and radiometric surveys. Apart from this the whole country is being surveyed by collecting geochemical and geophysical data (Ground magnetic and gravity). Therefore, India is also in the race with other countries in boosting critical mineral exploration. Since 170 years, GSI has been engaged in generating baseline data (Geological, Geochemical and Geophysical) and all the exposed areas have been critically explored and has contributed to the nation with many deposits. With the increasing demand for critical minerals the country needs to adopt the best practices followed in other developed countries in order to search for the concealed deposits in covered areas. The present paper deals with certain approaches in addition to what is being followed.

The critical minerals - present scenario

The group of 30 elements which are critical with respect to India (Ministry of Mines, 2023) are Antimony, Beryllium, Bismuth, Cadmium, Germanium, Graphite, Hafnium, Indium, Lithium, Niobium, Nickel, PGE, Phosphorus, Potash, REE, Rhenium, Selenium, Silicon, Strontium, Tantalum, Tellurium, Tin, Titanium, Vanadium and Zircon.

Antimony : Antimony is usually used as an alloying agent along with copper and lead to harden the products, with major use in battery industry to harden lead. It is also used as flame retardant. Antimony minerals and native antimony occur in hydrothermal veins within granite and carbonatite. It is also reported from skarns. GSI reported antimony from Barashigri, Himachal Pradesh (Srikantia *et.al., 1967)* and Pokhri, Chamoli district, Uttarakhand (Gopendra Kumar, 1963) in the form of hydrothermal veins in fractures within granite. There is no in-house production and India is completely dependent on imports from Tajikistan and Russia (IBM, 2022).

Beryllium : The major minerals of beryllium are chrysoberyl and beryl along with its gem varieties viz., emerald, heliodor, bixbite, goshenite etc. Beryl is mined from zoned pegmatites where the cores are often quartz rich and the margins contains beryl. However, secondary enrichment in regoliths and alluvial placers are also reported. GSI reported presence of beryl during mapping-from Phulbani, Odisha (Mishra and Udhoji, 1970). Present usage of it is in paper industry and India is completely dependent on imports.

Deputy Director General, Geological Survey of India
State Unit : West Bengal, Eastern Region, Kolkata

Bismuth : Bismuth is usually found associated with lead and zinc where it is accommodated in the lattice of lead sulphides along with silver and antimony. It is recovered as byproduct from the smelting of lead and copper ores. The major mineral bismuthinite occurs in hydrothermal veins within granite. Search for this element was attempted in Ajmer and Sikar districts, Rajasthan (Sen, 2014; Mukhopdhyay, 2000). India is completely dependent on imports.

Cadmium : Though cadmium forms its own mineral greenockite, it usually occurs in association with lead and zinc and is won as byproduct from smelting and refining of zinc ore where the concentration ranges from 0.03 to 9 wt% (IBM, 2022). It is a toxic element and has wide application in batteries and coatings (anticorrosive). India doesn't produce cadmium and is import dependent from Rep of Korea and Japan.

Germanium : Lead, zinc, germanium, indium and cadmium is a common association. Though germanium forms its own mineral which occurs along with copper-lead–zinc ores in carbonates or in hydrothermal veins, it is usually recovered from sphalerite which can accommodate upto 3000 PPM of germanium. Its main use is in electronics industry and presently the country's demand is met through imports.

Cobalt : There are very few cobalt deposits worldwide and mostly it is recovered as byproduct. Cobalt and nickel behave geochemically similar and forms Co-Ni-As sulphides (Cobaltite-Gersdorffite) but these do not form economically rich deposits. It occurs in mafic-ultramafic igneous rocks where it is associated with Cu-Ni- ±PGE or as hydrothermal veins along shear zones associated with Ag-Ni-Bi- ±U. It is also found associated with organic rich pyritic shale and sandstone deposited under reducing conditions with copper as major and cobalt as byproduct. Cobalt rich nodules are also reported from sea floor which can be a good source in future. The world famous cobalt deposit of Katanga Copper belt which accounts for 75% of the reserves occur in weathered argillaceous dolostones where cobalt is concentrated as capping due to supergene enrichment (Mambwe, 2022). In India, Cobalt occurs with nickeliferous limonite/laterite in Sukinda area, Jajpur district, Odisha. GSI reported 42311 tons of cobalt from the Sukhinda area (Chakravarthy, 1975). There is no inhouse production of cobalt and it is met through imports.

Copper : Copper occurs in a variety of geological settings. In the magmatic rocks it occurs in association with Ni and PGE as stratiform deposits at the base of a mafic-ultramafic complex. Few deposits are also reported in association with carbonatites, redbeds, basic volcanic rocks etc. A major source of copper is from the porphyry deposits formed along the convergent margins where the grade is low but with high tonnage. Another type is the structurally controlled hydrothermal veins where the grade is high in comparison to the magmatic types. The value of the ore increases if found associated with Au, Ag, Mo and Co but becomes problematic to beneficiate if found associated with As and Sb. In India, copper reserves are reported from a 100 km long Khetri belt, Rajasthan within the metasedimentary rocks of Ajabgarh Group of Delhi Supergroup; within tonalite- granodiorite rocks of Proterozoic age from Malanjhkhand, Madhya Pradesh and Ghatsila area of Singhbhum copper belt, Jharkhand. India has 163.89 mt of copper reserve and produced around 3.56 mt of copper during 2021-22 (IBM, 2022).

Gallium : Ga^{+3} is camouflaged into aluminium minerals as it possesses same charge and similar ionic radius. Therefore, 90% of the primary Gallium is won as byproduct from the aluminium production through Bayer process. Nepheline and alunite mined for aluminium too contains gallium. It is also extracted from the zinc sulphide residues. In India, gallium is produced by two plants which produces alumina viz., Hindalco Industries Ltd, Renukoot UP and Naltional Aluminium Company ltd, Damanjodi, Odisha (IBM, 2022).

Graphite : Graphite occurs both as syngenetic and epigenetic. Syngenetic graphite occurs as layers in metamorphic rocks while epigenetic occurs as veins intersecting pegmatite and metamorphic rocks. The source of carbon is from carbonate minerals where carbon is released through a reaction with hydrogen. India has 8.56 mt of graphite reserves (IBM, 2022) and the major production (63%) is from Tamilnadu. For ease of processing and better yield flaky graphite is preferred over granular ones.

Zirconium and Hafnium : Zr and Hf are closely associated with each other and their major mineral is zircon. Zircon usually contains < 5% HfO_2. Deposits of these elements form when zircon is released from the parent metamorphic rocks, granite, pegmatite and peralkaline rocks by the action of weathering and concentrated as river or beach placers. In India zircon occurs in association with other heavy minerals (ilmenite, leucoxene, rutile and monazite) in beach sands along the Indian coast and in the EEZ. Its concentration ranges from 0.6% to 18.7 %. Its major use is in the ceramic tile manufacturing. At present India imports zircon from Canada and China.

Indium : Indium is recovered from sphalerite as it replaces Zn in sphalerite. Though it occurs in native form and also combines with sulphur to from roquesite or indite, these never form economic deposits. India meets its requirement through imports. In combination with tin oxide it is used for manufacturing touch screens panels, solar panels, flat TV screens and microchips.

Lithium : Lithium is one of essential ingredients for battery. It has one advantage being recyclable from deposed batteries. The ionic radius of lithium does not allow substitution for most of the elements which form the bulk of the rock forming silicates. Therefore, lithium is enriched in the later differentiates or brines. Lithium bearing minerals viz., spodumene, lepidolite, zinwaldite, petalite and amblygonite are developed in Li bearing granitic pegmatites (LCT type). In India, the occurrence of spodumene is reported from Margalla-Allapatna, Mandya district, Karnataka and Rajgarh, Ajmer district, Rajasthan. GSI reported lithium mineralisation in the form of ferrisicklerite- triphyllite within pegmatite traversing meta-argillite from Kana-Rawat-ki-dhani, Rajathan (Chattopadhyay *et.al., 1995)*. Exploration for Li is also carried out in Rewat Hill, Degana, Rajasthan with Li values upto 3400 PPM along with W, Sn and Cs. Recently it is also reported from Salal- Haimana, Reasi district of the Union territory of J&K (Sharma and Uppal, 1995) associated with bauxite. India doesn't produce lithium and is completely dependent on imports.

Niobium and tantalum : Both niobium and tantalum are high field strength elements (ionic potential >2). These are incompatible because of high charge. Therefore, are concentrated in later differentiates of alkaline to acidic intrusions. Alkali granite and pegmatites are the major hosts for these elements. In India it is reported from pegmatite belts of Rajasthan, Chhattisgarh, Jharkhand, Bihar and Andhra Pradesh. India doesn't produce Nb and Ta and is import dependent. Brazil has 95% of the world's occurrence.

Nickel and PGE : The magmatic nickel deposits occur as stratiform Ni-Cu-PGE rich zones in the basal part of the layered mafic-ultramafic complexes. Sedimentary nickel deposits occur as Ni and Co bearing laterites formed over dunite and serpentinite. Therefore, ultramafic rocks are the major hosts for nickel and PGE. PGE in India is reported from Baula-Naushahi (3 km) belt in Odisha. India meets its requirement through imports and the demand may increase to 120 T by 2025. Nickel is reported from Ni-bearing limonite from Sukhinda and also along with uranium ores in Jaduguda, Jharkhand. At present India doesn't have the technology to extract nickel from the limonitic ores of Sukhinda, therefore, it is critical and the country solely depends on imports.

Phosphorus : Phosphorus combines with oxygen to give a variety of phosphate minerals (Nriagu, Moore, 1984). The Apatite Group and Al phosphate are important among them. The P_2O_5 content of apatite range from 36 to 42%. The primary phosphate deposits occur in acidic (granite and pegmatite), alkaline and carbonatitic rocks. Structurally controlled phosphate deposits comprise apatite veins in precambrian metamorphic terrains. The sedimentary phosphate deposits can occur as residual phosphate bearing laterites and bauxites developed over alkaline magmatic rocks. Phosphorus rich duricrust formed as a result of weathering of argillaceous and calcareous rocks (Aluminium- phosphate – sulphate APS duricrust and apatite bearing duricrust – APICRETES) too are good source of phosphates. India is deficient in apatite and phosphorite and is import dependent. The production is mainly from Jamarkotra in Rajasthan and Jhabua in Madhya Pradesh. Resources have also been reported from West Bengal and Jharkhand which are yet to be auctioned and mined.

Potash : The potash deposits are formed as a result of chemical precipitation of K-bearing minerals sylvite, carnallite and kainite from aqueous solutions under arid conditions where the evaporation exceeds the extra basinal inflow (evaporite). Glauconite bearing sandstone are also mined for potash. In India potash is found in Sawai Madhopur and Jaisalmer districts of Rajasthan and Sidhi district of Madhya Pradesh. These are associated with sedimentary rocks (evaporites, sandstone and shale). India at present doesn't produce potash and the requirement is met through imports.

Rhenium : Rhenium in nature is associated with molybdenum in molybdenite and is extracted from porphyry type deposits. Skarns formed in calcareous wall rock adjacent to intrusive granite, Cu- Mo-Ni- PGE bearing shale are also reported to contain molybdenite. It finds major usage in Aerospace and in super alloys. There are no reports of in-house production and is 100% import dependent.

Selenium and tellurium : These elements substitute S_2 in sulphides and are recovered as by-product mostly from anode mud obtained during electrolytic refinement of copper. These are found associated with porphyry copper deposits, massive sulphides and black shales. Se is used as decolourising agent and Te as an alloying agent to improve the machinability. India has the capacity to produce these elements in its Ghatsila copper smelter, Jharkhand, but is not being produced at present. The production directly depends on the supply of copper and nickel sulphide ores.

Strontium : Strontium (Sr^{+2}) replaces Ca^{+2} and Ba^{+2} in a variety of minerals. It also forms its own minerals viz., Celestite and Strontianite which occurs in evaporites and along with gypsum deposits in hydrothermal veins, carbonatites and in carbonates (limestone). India doesn't have any resources and is completely import dependent from China and Spain.

Tin and tungsten : These elements have different chemical properties, but are found associated together in nature. The major minerals of tin are cassiterite (78% Sn) and stannite (28% Sn). The major host rock for both the elements are the 'A' type and 'S' type granite and granitic pegmatite. These also occurs in skarns (proximal) developed in calcareous sediment in contact with a granite, post granitic endo and exogranitic greisen in 'S' and 'A' type granites, in fluvial and marine placers. Though tungsten is reported from Karnataka and Rajasthan where it is associated with quartz veins, India doesn't produce tungsten and the requirement is met through import from China and Korea. Tin is reported from Bastar and Dantewada districts, Chhattisgarh; Tosham in Haryana and Malkangire, Odisha within granitic pegmatites. India produced 26292 kg of tin concentrate in 2021-22 from Chhattisgarh (IBM, 2022). Cassiterite is mined from the river placers in Chhattisgarh.

Titanium and vanadium : Both the elements occur in association with iron in mafic intrusions more commonly with anorthosite - gabbro - norite association. In a closed system after the differentiation of anorthosite and norite/ gabbro, the residual melt is usually rich in iron and titanium. Ilmenite also forms a major constituent of the heavy sands/ beach placers. Vanadium in association with uranium occurs in arid duricrusts and calcrete, as nodules and pisoids in bauxite etc. In India, ilmenite, rutile and leucoxene occurs in association with other beach sands along the Kerala, Andhra Pradesh and Odisha coasts. India has 687 Mt of ilmenite and leucoxene reserves.

Rare Earth Elements : Out of 50 REE projects, 20 are in carbonatite/ weathered carbonatite and 13 in other alkaline silicate rocks indicating the importance of alkaline igneous rocks. The rest as beach/ river placers or associated with IOCG mineralisation. A majority of early production came from secondary deposits such as monazite-bearing placers. The total amount of REEs extracted prior to 1950 did not exceed 100 kilotons which is less than today's annual production. Advantage of palaeoplacers is its proximity to waterways and its association with other industrial minerals viz., zircon, ilmenite, rutile, cassiterite, U ores etc., and low processing cost (crushing charges reduced).

REE's are High Field Strength elements and immobile during weathering, therefore Weathering is another powerful mechanism for concentrating REEs and other rare metals showing limited mobility in surface waters.

Ion-adsorption clays developed from chemical weathering of granites added with a three- to five-fold enrichment of the laterite in REEs are another important type of surficial deposit. It is first identified in southern China in the 1970s and later from Madagascar, Laos, and other tropical to sub-tropical countries. These clays have low grades (≤ 0.3 wt% REO) but is preferred due to the presence of HREE and their amenability to open-cast mining and easy processing.

In India, apart from the beach placers, REEs are reported from Amba Dongar, Siriwasan-Nakal, Panwad-Kawant in Gujarat; Kamthai, Mer-Mundwara, Niwania in Rajasthan; Samchampi, Barpung, Jarsa in Assam and Sung Valley in Meghalaya. All are hosted in carbonatites. The Deformed alkaline rocks and carbonatites (DARCs) in the Great Indian Proterozoic Fold Belt where Forty-seven DARCs are known from within the 4000 km long mountain belt also are potential for REE. India has 12.73 mt reserves of monazite found in the inland and beach placers.

Future outlook

Out of the 30 critical elements 10 are recovered as byproducts which substitute a major element. Except Ga and Hf the production of the remaining 8 elements depend on (a) supply of Cu-Pb-Zn sulphides (b) improvement in beneficiation techniques. The low grade ores which were hitherto discarded needs to be revisited to see the presence of these elements in the light of improved processing techniques over the years. The exploration strategy needs to be redesigned by adding to the existing base line data. Identification of the mineral system, concept based modelling, dating of the metallogenic provinces, study of stable isotopes, generating litho maps containing granite and pegmatite and targeting concealed deposits through integration of geophysics and geochemistry should be made a part of the approach.

Geological system which operated for millions of years are instrumental in bringing out mineral deposits as products. The various geodynamic processes which operate in different tectonic settings result in the formation of various mineral systems. The porphyry copper molybdenum system, VHMS (Cu-Pb-Zn) system, Orogenic gold deposits, IOCG (Cu-Au-Fe) system, intrusive related W-Sn-Mo-Au-Cu system form in the convergent tectonic setting while the mineral systems associated with the divergent tectonic setting are unconformity related U, Cu-Co associated with shale, mineralisation associated with alkaline magmatism etc. Orthomagmatic Ni-PGE systems associated with Large Igneous Provinces, potash and phosphorite systems forms a part of the Intra plate setting.

Isotope mapping

Isotope maps of the cratons covering the obvious geological potential areas will help in understanding the variations in litho assemblages with time, including when mineral systems were active, and will assist in predicting the likely distribution of undiscovered mineral resources. The country already has very good quality baseline data viz., geological maps in 1: 2 million scale, 1:50, 000 scale and 1: 25,000 scale (partly); geochemical data of the entire country on 1: 50,000 scale for 64 elements; geophysical (gravity and ground magnetics) on 1: 50,000 scale.

Isotopes help in understanding the mineralizing processes from sub-microscopic scale to cratonic scale. The study of the isotopes will be of immense help to determine (a) the absolute timing and duration of mineralizing processes (b) metal sources, fingerprint deposit types and map tectonic, metallogenic provinces. (c) fluid and sulphur sources and establish ore forming reactions and processes (d) geochemical processes of mineralisation (Springer, 2023).

The major application of the radiogenic isotopes is in dating the geological events. The availability of the required instruments was a main constraint earlier. But in the recent times, the country has procured many TIMS, SIMS and LA-ICP-MS which will help in formulating national level projects and aid faster analysis of the data.

The main radiogenic isotopes used in Geochronology are (a) U-Th-Pb (b) Re-Os (c) K-Ar (Ar-Ar) (d) Rb-Sr and (e) Sm-Nd. Care must be taken in interpreting the data. If a mineral system remains open for an extended period of time or reopens later due to some tectonic process then the age determined may not reflect the primary ages of mineralisation. By far the best understood isotopic system to determine the ages in most geological system and mineral system is the U-Pb system (Chelle-Michor and Schalteffer, 2023). U-Pb isotopes give the absolute ages of the mineralizing events and magmatic rocks. The Re-Os system is also used to date a mineral system and depends on the availability of molybdenite, arsenopyrite and pyrite. It gives valuable inputs with regard to metal sources and partitioning of PGE between sulphide and silicate melts in the understanding of orthomagmatic systems. The Sm-Nd isotopic composition of acid magmatic rocks provide a broad understanding of the bulk crustal age. The Pb isotopic composition (Pb-Pb system) of the lead sulphides gives an understanding of the isotopic composition of the fluids from which those sulphides were derived, the source of the fluids that have transported the metals etc. The K-Ar and Ar-Ar system can date many events viz., magmatic crystallization, metamorphism and mineralisation. Stable isotope data on the other hand can detect a concealed deposit through secondary dispersion based on the differences in isotopic signatures of mineralized and un-mineralized hosts. Cu isotopes are found to be more useful for this. Oxygen isotopes too can provide information on temperature of mineral formation and source of fluid.

Isotope mapping starting with U-Pb and Pb-Pb can be taken on national scale in collaborative mode involving all the laboratories having such instruments. More than 16 minerals are being used for dating using the U-Pb method viz., zircon, baddeleyite, titanite, monazite, xenotime, calcite, garnet, cassiterite, columbo-tantalite, uraninite and wolframite. It is used to date a geological event related to a mineral deposit, the data can be of help to search for a deposit in unexplored area of the same age and similar setup. It can decipher duration of an ore forming process and date the multiple geological events associated with mineralisation as used in the case of Witwatersrand gold province (Chelle-Michou and Urs Schaltegger, 2022).

Magnetotelluric and seismic studies

There is steep decline in the discovery of new mineral deposits during the past 20 years and all the known deposits are almost exploited. Therefore, to increase the chance of discovering concealed and deep-seated mineral deposits below a cover, apart from isotope maps, systematic collection of high resolution Magnetotelluric data, Electromagnetic data and seismic data is warranted. National Mineral Exploration Policy 2016 directed GSI to initiate projects for identifying concealed deposits. Based on which GSI has started the 'Project Uncover' in collaboration with Geo Science Australia.

Magnetotelluric method is a passive geophysical method which measures the electrical resistivity of the subsurface using natural time variations of earth's magnetic and electric fields. MT helps in identifying deep mineralised fracture clubbed with seismic data can generate wonderful results since, seismic studies gives an image of the subsurface. MT uses naturally occurring broad band EM waves such as those generated from thunderstorms or due to the interaction of solar wind with earth's magnetic field to give a subsurface resistivity structure. These are measured over a range of frequencies from 10000 Hz to 0.0001 Hz where low frequency waves can penetrate to a very great depth.

MT provides the dimensions and extent of a mineralised deep fracture while seismic data gives the thickness of cover sediments over it. Therefore, the depth at which such structure is present can be ascertained by integrating MT and seismic data.

Conclusion

Apart from the 30 minerals listed, India needs to search for many other minerals which may become critical in the near future. The existing data will be a strong base over which new data can be generated. Concept based approach with an understanding of the geodynamic processes and the related mineral system can be adopted. Best practices followed in other developed countries which includes generation of isotope maps and other litho maps should be the approach to understand the geology, date the geological events and record the time when the mineral systems were active. In addition to this Magnetotelluric studies integrated with seismic data can be used for mineral search.

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SYNOPTIC APPRAISAL OF SOME OF THE CRITICAL MINERALS BELONGING TO RARE METALS (RM) AND RARE EARTH ELEMENTS (REE) GROUP IN THE INDIAN CONTEXT

Dr. S. K. Biswas

Introduction

Critical minerals of any country are the metallic and nonmetallic elements which are essential for the functioning of modern technologies, economics and national security with a risk that the supply chain could be disrupted. The minerals are not uniform in all the countries. Depending on geological evolutionary history, elemental distributions are highly skewed and each country has its own list of critical minerals influenced by its economy, industry requirements, security concerns, technology, natural resource endowment and geo-political factors. Each country is trying its best in the rush to have access to critical minerals.

In Indian context, economic importance, technology and supply risk were the most important parameters to identify 30 critical minerals which included antimony, beryllium, bismuth, cobalt, copper, cadmium, gallium, germanium, graphite, hafnium, indium, lithium, molybdenum, niobium, nickel, PGE, phosphorous, potash, REE, rhenium, silicon, strontium, selenium, tantalum, tellurium, tin, tungsten, titanium, vanadium and zirconium. Subsequently 24 elements included under critical minerals are beryl and beryllium bearing minerals, cadmium, cobalt, gallium, glauconite, graphite, indium, lithium, molybdenum, nickel, niobium, phosphorous, PGE, potash, REE, rhenium, selenium, tantalum, tellurium, tin, titanium, tungsten, vanadium and zirconium as per Mines and Minerals Development and Regulation (MMDR) Act 1957.

Uses : Critical minerals are necessary components for a wide range of modern applications especially high tech consumer products (mobile phone, computer components, flat screen monitor, television, superalloys, pigments, ceramics, electric vehicles) and other applications are phosphors, lasers, super conductors, data storage, optical fiber, permanent magnets, jewellery, electron microscope, magnetic refrigeration, medical devices, nuclear uses, solar energy system, lubricants etc. The uses are many more in the modern technology.

The critical minerals are naturally occurring and their individual abundances are by no means equal in the continental crust. The deposits are formed by concentration of the most and least abundant elements typically differing by varied orders of magnitude. As technological applications have multiplied in the last decade, demand for several less abundant critical minerals have increased dramatically. Different elements have different uses with an ultimate goal of energy transition and net zero emission. Critical minerals like copper, lithium, nickel, cobalt and REE are important components in emerging green technologies like wind turbines and electric vehicles. Lithium-ion batteries are most important to reduce carbon emissions. Long range car batteries require

(Retd. Director) GSI

graphite as anode material. Colour cathode ray tubes and liquid crystal displays used in computer monitors and televisions employ Eu as the red phosphors, no substitute is known. Fiber-optic telecommunication cables use Er as this alone possesses the required optical properties. Ce has dozens of applications, some highly specific. REE magnets reduce weight of automobiles. Y, La, Ce, Eu, Gd, Tb used for energy efficient fluorescent lamps to reduce energy consumption and CO_2 emissions. Magnetic refrigeration is new technology with use of newly developed alloy Gd_5 (Si_2 Ge_2) which reduces toxic gases damaging ozone layer, ultimately delaying global warming. REE like La, Ce, Pr and Nd are most common while Gd to Lu, Y are more valuable and scarce in deposits.

In general, it is observed that RM and REE are majority of the critical minerals in India and those are briefly focused in this write up.

Occurrences in India :

1) Rare Metals (RM) : RM is discussed in general with emphasis on lithium which is required for lithium-ion battery. The RM, in general, occur in pegmatite though other types are also known. The most important pegmatite belts in India are located in Rajasthan, Jharkhand and Andhra Pradesh. Pegmatite belts of less prominence hosting Ta, Nb, Li, Be, Cs with or without tin occur in Chhattisgarh, Odisha, Karnataka and Tamil Nadu (Banerjee, 1987, 1999). RM bearing pegmatites occur in different ages ranging from Neo Archaean to Pan African age, very few between 1600-1200 Ma.

RM bearing pegmatites belong to special class being highly differentiated product of fertile granite (Banerjee. *et.al.,1983)*. The mineralizations occur in pegmatite as well as outside the granitic pluton within low pressure Abukuma type of metamorphic rock belonging to amphibolite to upper greenschist facies (Winkler, 1967). Cerny (1989) classified zoned pegmatite as RM bearing and classified it into a) rare earth type, b) beryl type, c) complex type, d) albite-spodumene type and e) albite type. Genetically RM pegmatites are classified into LCT type with Li, Rb, Cs, Be, Ga, Sn, Ta> Nb; NYF type with Ti, Y, REE and Nb>Ta and mixed type (Cerny, 1991). Zoning is defined on the basis of mineralogy and texture.

Although RM pegmatites are located in different geological domain, economic potential depends on several factors mainly, reaction of first formed minerals with progressively changing residual magmatic fluid from the outer to inner zone, evaluation of terrain, geological criteria, geomorphology etc. Petrological, geochemical and tectonic classification of rocks are to be conceptualized to target new areas for Reconnaissance (G-4). Carbonatites and some of the peraluminous granite do contain a few of the RM. Though RM pegmatites is a source of Li, the element can be present in other geological domain also. Extractable lithium minerals associated with pegmatites are spodumene, lepidolite, petalite, amblygonite and eucryptite (Evans, 2014). Lithium is one of the secondary mineral occurring in aluminous laterite in Jammu and Kashmir. According to Cao and Li (2017), in secondary environment lithium can reach upto 0.3% Li_2O. Salar brine deposits known as hectorite jadarit, continental, geothermal and oil field types are, so far, unknown in India. Metasomatic skarn rocks of Rajasthan contain some of the RM. It requires to be remembered that vein type of deposits have a stray narrow pattern of anomalous abundances of ore elements in the wall rocks close to the mineralization, sometimes restricting to a few meters and rarely exceeds more than 50m.

2) Rare Earth Elements (REE) : The REE form a series of 17 chemically similar elements, the 15 lanthanides (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) plus Y and Sc. REE have very little tendency to concentrate in the ore deposits. The lighter REE (LREE) are more incompatible and strongly concentrated in the continental crust than the heavier REE (HREE). In most REE deposits the first four LREE i.e. La, Ce, Pr and Nd are more common, but the HREE like Gd to Lu are less common and more desirable. The most common minerals that are processed to recover the rare earths are bastnasite, monazite, loparite, parisite, xenotime, ionic clays and apatite. REE can be recovered from allanite also.

Hard rock deposits of bastnasite and placer deposits of monazite and xenotime contain most of the world's economic concentration of LREE and those have been exploited maximum for REE. World production of bastnasite is mainly from Inner Mongolia as a by-product of iron ore mining. Monazite and xenotime are obtained as by-products of titanium and tin production, quite often from placer deposits (Beach and inland placers). The less abundant but more valuable Y and HREE are mainly sourced from ion adsorption clays in lateritic weathering crust. Xenotime is a source for HREE.

Since discovery up to 1950, a few of the REE were produced from monazite bearing placers and veins, from pegmatites and carbonatites and as minor byproducts of uranium and niobium extraction. During 1965 onwards, major source of LREE was from carbonatite of Mountain Pass, USA. China, the major producer, contributed REE mainly from two sources i.e. bastnasite from iron–niobium-REE deposits and ion-adsorption clay in lateritic crust. Bastnasite the main REE bearing mineral occurs dominantly in carbonatite and hydrothermal (iron oxide- Cu-Au-REE) IOCG deposits in Olympic Dam, Kiruna etc. The other source rocks are nephelene syenite, peralkaline-alkaline felsic rock etc. Monazite is the singlemost main REE mineral occurring in placers. Zoned pegmatites do contain REE.

Many countries are producing REE from different sources.

Indian Scenario : India is not at all in a comfortable position with respect to rare metals clubbed under critical minerals. Almost all the metals are imported, majority reaching upto 100% import. Lithium is the key ingredient in rechargeable batteries used in EVs and there is a huge need to access the raw materials. Pegmatites at places are relatively enriched in lithium content. India has plenty of monazite placers, a source metal for REE, in the beach sands and some quantity as inland placers. Monazite contains mainly LREE, not fulfilling demands for HREE and thorium associated with it is radioactive. There are number of carbonatite bodies in the country from Archaean to Cretaceous containing REE, but so far economic deposits are yet to be established, but in general it is observed that Amba Dongar and Kamthai carbonatites from western India are rich in bastnasite and some resources have been calculated (Singh, 2023). In addition, local enrichments of RM/REE have been noticed in albitites, pegmatites, A-type granites, syenites, anorthosites, phosphorites, apatite-magnetite, carbonaceous schists and coal. Coal ash, acid mine leach, waste material in mine have a potential.

Scope for search within country : In India, the geological melieu for RM and REE mineralization exist in space and time and data were collected over years, hence it is essential to collate and examine those data generated from Archaean to Proterozoic to younger granitoids and related pegmatites, metasomatic skarns and hydrothermally altered zones, albitites, carbonatites, syenites, anorthosites and also their supergene enriched profiles. The basis for any ore deposits are source material, transport of components in the deposits, a depositional mechanism and geological processes which preserve the deposit. Ore deposits represent anomalous crustal accumulations of particular or a group of elements. They show depletion and enrichment of elements relative to their enclosing host rocks. After proper evaluation of existing data along with identification of mineral phases, there is strong possibility that we can target suitable areas for search of RM and REE. Search for salars may be extended to Western India and also in the geothermal and oil fields. Data from coal basins and metalliferous black shales need to be studied to examine possibility of RM / REE in these rocks.

Once based on known occurrences, modelling, geochemical and tectonic evaluation, target areas are identified, sampling programme needs to be initiated depending on geology and geomorphology.

Options open to India : In developing country like India, critical minerals are a critical opportunity to create jobs, diversify economics and boost revenues. The most important is beneficiation, extraction and processing techniques for the production of critical minerals deemed critical to support an economical, environmentally benign and geopolitically sustainable domestic supply chain. If indigenous production is in forefront, import will come down and this will give a boost to the manufacturing of superalloys which are widely used in high growth industries like clean energy, defense, space and EVs etc.

India needs to act fast on exploration, excavations and setting up critical minerals value chain through adequate downstream investment. The need of the hour is robust exploration and utilizations of critical minerals to support the nation's rapid growth and clean energy aspirations.

Actions taken in India : India has taken proactive role to come in the forefront to assure critical minerals supply and end uses. It has been realized that domestic raw material industry and manufacturing growth is possible only when supply is fuelled by domestic sources. One of the schemes is to boost exploration activities in the country to identify new deposits. Initially the Government agency like GSI went on increasing their exploration items on critical and strategic minerals annually for last couple of years reaching 125 projects in the field season 2023-24, aspiring 188 items during field season 2024-25, mainly using budgetary fund. MECL, the Public Sector Undertaking also gave emphasis on exploration of critical minerals. To increase self reliance and steady domestic supply the central government has made several policy reforms to boost mineral productions through repeated amendments of MMDR Act,1957 which are :

1. Minerals which were under Atomic Mineral Group, explored by AMD only, few of them were excluded and permission was given to other Government Agencies to carry out exploration.
2. Schemes were made for engagement of Notified Private Exploration Agencies (NPEA) for exploration of critical and strategic minerals (listed in the Part D of the First Schedule and Seventh Schedule of the MMDR Act, 1957) by the process of reimbursement/funding operations through National Mineral Exploration Trust (NMET).
3. Relaxation of maximum area by exercising power the lease areas for Prospecting License and Mining lease were increased to 100 sq.km and 50 sq.km respectively.
4. GSI and MECL explored blocks are put under auction for acceleration of exploration activities. Some of the major PSU's have shown interest in the endeavour.

   Although, RM and REE are in great demand, main thrust is for lithium which is the key element for lithium-ion batteries and EVs to reduce carbon emission. In search for lithium, in addition to India, attempts are being made to access property in abroad. Coal India, ONGC Videsh, NMDC and KABIL are engaged in scouting for critical minerals assets in Chile, Bolivia and Argentina. India is looking for Africa, from countries like, Zambia, Namibia, Congo and Ghana.India became member of the Mineral Security Partnership (MSP) to seek to bolster critical minerals supply chain to support climate objectives.

   Overall a positive attitude is observed at all levels to assure critical mineral supply chain.

Conclusions : Although we have many hard rock prospects of RM and REE in India, monazite from beach sand placer deposits is the main source of REE. Some of the RM from pegmatites have been produced and stock piled. There is no deposit of lithium, the most wanted rare metal. HREE and many of the RMs India is in a scarce position depending 100% on import. Robust exploration activities within the country both by the government and private sectors are need of the hour. Value addition by beneficiation and processing technology within the country should be the choice to guarantee supply chain. Earlier only AMD was empowered to carry out exploration for RM/REE. Subsequently exploration activities were extended to other Government agencies and, of late, private sector has been permitted to carry out exploration through repeated amendments of MMDR Act. Till now GSI is the major exploration agency looking into exploration issues in the national level followed by MECL for G-4 level (Reconnaissance) exploration. Participation of private sector (NPEA) utilizing NMET fund is a new step which needs acceleration. G4/G3 level explored blocks of GSI, put forward for auction, are not showing much interest by the private sector having vast experiences of mining, rather some of the Central PSUs have shown interest. It is felt that before auction all the clearances must be accorded by the respective state government for a hassle-free exploration. In addition to auction, it can be thought by the competent authorities to allow private players directly for (G-4) exploration on the basis of FCFS, followed by upgradation of exploration stages to mining through automatic route. Private players with knowledge of state-of-the-art technology for RM/REE explorati on should be allowed to select areas for G4 exploration of their own choice.

The government agencies are expected to take due care during initial stage of sampling considering geological, geochemical and tectonic classifications of rocks, notably granites, dispersion patterns in primary and secondary environments and grain size distribution. Geophysical survey and spectral survey from remote sensing must consider mineralogical assemblages. During stages of exploration specific need for drilling /pitting have to be understood clearly. Assessment will depend on exploration methods, sampling strategy, procedures and accuracy. Chemical analysis supported by mineralogical association will help prospect evaluation. Beneficiation and processing technology would be the ultimate goal.

Due to critical mineral emergence as a new player and India a serious contender in energy transition has to take many steps particularly in processing technology where incentives and tax benefits may be thought to boost lithium process.

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