MGMI
News Journal

Vol 49, No.4
January - March 2024

Established 1906

THE MINING, GEOLOGICAL AND METALLURGICAL INSTITUTE OF INDIA

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THE MINING GEOLOGICAL & METALLURGICAL INSTITUTE OF INDIA
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MGMI NEWS JOURNAL

Vol. 49, No. 4 ● January - March ● 2024

THEME

"Sustainability in Metals Minerals and Materials"

ISSN 0254-8003

The Mining, Geological and Metallurgical Institute of India

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A Quarterly Publication
MGMI NEWS JOURNAL
Vol. 49, No. 4, January - March, 2024
ISSN 0254-8003

CONTENTS

PRESIDENT'S MESSAGE

Traditional mining engineering curricula often drew a distinction between coal and metal (non-coal) mining. There are obvious reasons to do so as the nature of mining activities, economic prospects and regulatory norms required for both have traditionally been different. And while both sectors have contributed to economic growth of the country, the modes of contributions have been different. According the NITI Aayog's India Climate and Energy Dashboard, more than 85% of domestically produced coal is used for power generation. In the days to come, however, one could foresee much more integration and complementarity of coal mining on one hand, and minerals on the other. In this vein, I am delighted that the editorial board has chosen "Sustainable Metals, Minerals and Materials" as the theme of this issue of MGMI News Journal. The technical papers as well as the interview with our Past President, Dr N K Nanda, present unique insights from distinguished individuals with several decades of experience in the area.

The Hon'ble Prime Minister of India has stressed upon Panchamrit as the future development strategy of the country. This entails 50% of energy requirements being met by renewable sources by the end of this decade. India is well on its way to meet this ambitious goal. Currently, Coal India Limited, NLC India Limited and SCCL have already installed 1.7 GW of solar capacity. By 2025-26, Coal India aims to install 3 GW solar capacity and 2 GW of other renewable capacity enroute to meeting its corporate net-zero target. Growth of solar and other renewable energy does not exist in isolation. Setting up of this infrastructure is associated with requirements of critical minerals. For instance, a solar plant requires nearly three times as much minerals per MW capacity as a coal-fired power plant. The nature of minerals is also diverse. Most recent data from the International Energy Agency shows that 4,000 kg silicon/MW solar capacity will be required. Critical mineral requirements are even higher for wind plants, with an offshore wind plant requiring nearly six times as much minerals as compared to a coal-fired plant, with most requirements pertaining to zinc.

These changing dynamics will create new barriers and facilitators in the years to come. India is a major exporter of zinc. Silicon market is a more difficult to navigate. Silicon production in India is rising steadily. But the key projected demand for this mineral will be in the semiconductor sector. Meeting large demands across the energy system and information technology sector would require increase in mining capacity for silica. This could result in economic improvements in states like Odisha. At the same time, silicon mining can pose issues to the water environment of the community. Thus, a comprehensive strategy is required for meeting these requirements.

The situation is even more challenging when we look at the transport sector. Lithium is an essential component for producing electric vehicles (EVs). EVs currently constitute only 2% of the light-duty vehicle segment but may be poised to increase to 30% by the end of this decade. This will place large lithium requirements on the economy. Currently, India imports all of the lithium used. That said, new lithium deposit discoveries were made in Jharkhand, Rajasthan and Jammu & Kashmir. One new production method for lithium has emerged, which is known as direct lithium extraction from brines. Much of this development is being spearheaded by startups in the West. I would encourage our young entrepreneurs to try to find out if similar opportunities could be found in Indian context. Recent research from the University of Texas at Austin has shown high lithium content in oilfield brines in the state of Texas. These brines are often accompanied with high potassium and boron content. Similar screening efforts should be taken at high priority at our universities and research institutes. At the same time, India is already leveraging its diplomatic relationships with the Quad nations, Latin America and Sri Lanka for multilateral and bilateral partnerships. Having robust diplomatic relationships will help foster resiliency in the critical minerals sector.

In addition to these minerals, there is a great demand projection for novel materials in the future. An example is that of carbon nanotubes (CNT), which has wide-ranging applications in the industry. Bhabha Atomic Research Centre has developed advanced catalysts for synthesis as well as surface modifications of CNT. There is also a scope for utilizing traditional science in this area. Research sponsored by the Department of Science and Technology and published in the Scientific Reports journal has demonstrated that ancient potteries found in Tamil Nadu from the sixth century BC contained single-walled nanotubes. There are also potentially opportunities to convert coalbed methane and coal mine methane from Raniganj, Jharia and Bokaro coalfields into CNTs. Again, this is an emerging challenge for young scientists and engineers across the country.

These challenges are multifaceted and cannot be accomplished by a single discipline. Collaboration is required across diverse branches of science, engineering and business to develop novel extraction and synthesis technologies. Technologies would also need to be tailored to Indian conditions. The revenue opportunities emerging from such avenues will be very significant. Interesting fundamental research sponsored by the Government can be translated into a commercial scale with the participation of the private sector. Thus, sustainable minerals, materials and metals can be a future success story for public-private partnership in our country.

Dr B Veera Reddy

President, MGMI

Director (Technical), Coal India Limited, and

Chairman-cum-Managing Director, Central

Coalfields Limited

EDITORIAL

SUSTAINABILITY IN THE METALS AND MINERALS SECTOR

The sustainable management of metals and minerals is pivotal for the economic, environmental, and social well-being of any nation. These finite resources serve as the backbone of modern industry, contributing to sectors ranging from infrastructure development to advanced technology manufacturing. Ensuring their sustainable extraction, utilization, and recycling is imperative to meet present needs without compromising the ability of future generations to meet their own. Nations endowed with significant mineral wealth face both opportunities and challenges in harnessing these resources responsibly. Understanding the occurrence and mining of minerals is crucial for striking a balance between economic development and environmental preservation. Sustainable mining practices not only mitigate environmental degradation but also promote community welfare and resource longevity. As countries navigate the complexities of mineral resource management, integrating principles of sustainability becomes increasingly vital for fostering resilient economies and safeguarding the planet's ecological integrity.

From ancient civilizations to modern industrialization, minerals have played a vital role in shaping India's developmental journey. Ancient texts like Kautilya's Arthashastra, dating back to 300 BC, have documented various minerals, including gold, diamonds, and others. The Hutti Gold Mines, tracing their origins to 760 BC, and the lead-zinc mining at Rajpur Dariba, believed to have begun approximately in 1260 BC, serve as evidence of India's extensive involvement in mineral extraction over the centuries. The discovery of the famed Kohinoor diamond in Guntur district underscores India's historical significance in treasure excavation, exemplifying the nation's enduring link with its mineral wealth.

India is endowed with an abundance of a wealth of 87 minerals, including 23 minor minerals (including building and other materials), 22 non-metallic minerals, 11 metallic minerals, 4 fuel minerals, and 3 atomic minerals. The major and minor minerals have been listed in the Mines and Minerals Act 1957. National agencies such as the Geological Survey of India (GSI), Indian Bureau of Mines (IBM), Mineral Exploration Corporation Limited (MECL), Oil and Natural gas Corporation Limited (ONGC) and various state geological departments diligently update the inventory of both major and minor minerals on an annual basis. Fossil fuels, particularly coal and lignite, reign supreme in the realm of mining, with nearly 400 mines dedicated to their extraction, while another 350 category A mines focus on metallic minerals. Since 1971, the public sector has taken the helm in coal mining, overseeing the majority of operations. Ownership of non-coal mineral leases ranges from private entrepreneurs to state undertakings, with mining practices spanning from manual labour to intensive mechanization.

The country possesses plentiful reserves of iron ore and bauxite, along with sufficient reserves of chromite, manganese, and zinc. These minerals are predominantly found in podiform, stratified, sedimentary, or meta sedimentary deposits, occurring in oxide or sulfide forms. Stratified deposits of bauxite, iron, and manganese typically have minimal overburden. Chromite deposits in Odisha are situated within ultra-basic peridotite intrusions in the parent rock. Mining operations targeting weathered dunite-peridotite ultramafic complexes, rich in chromium and nickel, are conducted through opencast methods at depths ranging from 30 to 70 meters. The majority of lead, zinc, copper, gold, and manganese deposits were found beneath deep cover, while only a few surfaced in pockets, influenced by weathering and secondary enrichment characteristics.

Various industrial minerals, including sedimentary deposits of building materials like limestone, dolomite, marble, and slate, are found in abundance. Deposits like gypsum and anhydrite, alongside valuable resources like phosphate, potash, vermiculite, kaolin, and fire clay, among others, are found. The geological landscape presents limestone, dolomite, and marble in near-flat beds that often outcrop or are found cropping under a thin burden. Similarly, resources like gypsum, fire clay, fuller's earth, and bentonite are typically located near the surface, often under a thin protective cover.

The economic significance of mineral wealth has seen a remarkable surge alongside industrialization. According to the estimates provided by Annual Report of the Ministry of Mines estimates, the total value of mineral production (excluding atomic, fuel minerals, and minor minerals) is estimated at Rs.107,446 crores in the fiscal year 2022-23. Metallic minerals accounted for Rs.95,838 crores or 89% of the total value, while non-metallic minerals (excluding Minor Minerals) contributed Rs.11,608 crores or 11% of the total value during the same period. Notably, the wholesale price index (WPI) for minerals (base 2011-12=100) stood at 196.7 in November 2022 and the corresponding index was 190.3 for November 2021. The minerals included in the WPI are bauxite, chromite, iron ore, copper conc., lead conc., garnet, zinc conc., manganese ore, limestone, phosphorite, and sillimanite.

According to the World Mineral Production report spanning from 2016 to 2020 by the British Geological Survey, India held the second position globally in steel (crude/liquid) production, followed by third place in zinc and aluminum (primary) production, ranked fourth in chromite and iron ore production, fifth in manganese ore, sixth in bauxite, seventh in refined copper, fifteenth in apatite and rock phosphate, and seventeenth in magnesite. As such, India remains largely self-sufficient in minerals, providing primary mineral raw materials essential for various industries.

Metals and minerals, therefore, hold a crucial position in India's economic landscape, driving financial stability through their intrinsic value, job creation potential, and revenue generation. While the mining sector's direct contribution to the gross domestic product (GDP) remains relatively modest, ranging from 2.2% to 2.5%, its significance within the industrial sector is remarkable, accounting for approximately 10% to 11%. Moreover, the sector plays a vital role in employment generation, with nearly 1.3 million individuals employed in India's mining industry during the fiscal year 2022-23.

India's rich mineral wealth has fueled economic growth and supported diverse industries, from traditional crafts to cutting-edge technologies. As the country strides towards sustainable development, responsible mining practices are paramount. Balancing the exploitation of mineral resources with environmental conservation and social welfare is a pressing challenge. Embracing sustainable mining methodologies not only ensures resource longevity but also fosters equitable growth and safeguards the environment for future generations, aligning with India's vision of inclusive and environmentally conscious development.

In addition to the imperative of responsible mining practices, it is crucial to consider the broader environmental impacts of industrial activities. Assessing carbon and water footprints becomes integral in gauging the sustainability of mining operations. The carbon footprint measures the total greenhouse gas emissions, including carbon dioxide, methane, and nitrous oxide, associated with mining activities. Water footprint analysis, on the other hand, evaluates the volume of water consumed and polluted throughout the mining process. Both metrics underscore the necessity for a holistic approach to sustainable mining, one that not only minimizes immediate environmental harm but also addresses long-term ecological consequences. Achieving net-zero emissions in mining operations emerges as a crucial goal in mitigating climate change and preserving natural resources. By integrating strategies for carbon neutrality and water conservation into mining practices, India can exemplify global leadership in sustainable resource management. Embracing the principles of net-zero emissions not only aligns with India's commitment to responsible development but also ensures a legacy of environmental stewardship for generations to come. Thus, as India continues its journey towards sustainable growth, it must prioritize not only responsible mining practices but also the imperative of achieving net-zero emissions to safeguard the planet and promote equitable prosperity.

The current edition of this journal concentrates on fostering sustainability in the metals and minerals sector. The Editorial Board expresses gratitude to Past President, Dr N K. Nanda, for generously sharing his insights on the subject during an interview. We express our heartfelt appreciation to the authors for their valuable contribution of relevant technical articles for publication and genuinely wish that the readers will discover this issue to be both captivating and beneficial.

Ajay K Singh

Honorary Editor, MGMI

NATIONAL SEMINAR ON ARTIFICIAL INTELLIGENCE IN MINING

MUMBAI CHAPTER

The mining industry is undergoing a significant transformation, propelled by the integration of Artificial Intelligence (AI) across its value chain from exploration, operations, maintenance, mineral processing and environment management. This transition marks a move from traditional methods to a technologically advanced approach. The mining industry is embracing a significant shift towards AI-driven exploration and operations across the supply chain. This transition is not just an incremental change but a fundamental revolution in how the industry operates. In this background, a Seminar on 'Artificial Intelligence in Mining' was organised by MGMI Western Region at Hotel Sofitel, Mumbai on 26th February 2024.The event was inaugurated by the Chief Guest of the Inaugural Session Dr B Veera Reddy, Director (Technical), Coal India Limited and President, MGMI in presence of the Guests of Honour, Mr. A K Singh, Director (Technical), Western Coalfields Limited and Mr. Thomas M Cherian, Managing Director, Essel Mining & Industries Limited and Vice President, MGMI.

Six notable speakers delivered presentations on various aspects of artificial intelligence and digitalization in the mining industry, a summary of which is described below :

Mr Manish Gupta, CIO, Aditya Birla Group, discussed the potential of artificial intelligence in the mining sector. He covered topics such as digitalization opportunities, AI's role in ensuring smart, safe, and sustainable mining, and its impact on productivity, environmental and social aspects, as well as cost control and resource development.

Prof Siddhartha Agarwal from IIT (ISM) Dhanbad highlighted digitalization trends in global mining and practical applications of AI and machine learning. He discussed the importance of AI in mining operations, modelling mine operations, data sources, and various applications of AI along the mining chain, emphasizing predictive analytics and the challenges and benefits associated with AI adoption.

Mr Ranajit Sahu, Managing Director at Accenture, presented on digital transformation in mining, focusing on Generative AI (Gen AI) and its potential to enhance business value across the mining value chain. He discussed the evolution of technology, the significance of Gen AI for industries, fundamental Gen AI models, and multiple use cases for Gen AI implementation in mining, such as ML-driven prospectivity analysis.

Mr Tycho Möncks, Managing Director & Partner, Industrial Goods Practice, Boston Consulting Group addressed the imperative of organizational and human transformation for successful AI implementation. He emphasized the importance of people and process changes, highlighted common reasons for AI project failures, and provided insights on how companies can maximize value from AI by focusing on people, prioritizing value, and ensuring business ownership.

Dr Anand Kumar Singh, Associate Professor, Department of Earth Science, IIT Bombay, explored the role of machine learning in joint geophysical imaging. He discussed the motivation behind using machine learning algorithms, compared different modelling approaches, and shared case study results and validation techniques, emphasizing the importance of utilizing multiple geophysical data sets for accurate subsurface information.

Mr Pranav K, Partner Digital Transformation, Grant Thornton, delved into AI trends, use cases, and approaches in the mining industry. He discussed key trends driving digital and AI disruptions, particularly in miner safety, and outlined potential approaches for AI implementation in mining operations.

The session concluded with remarks from Mr. Thomas M Cherian, Managing Director, Essel Mining & Industries Limited, and Vice President, MGMI.

Calcutta Chapter

ANNUAL GET-TOGETHER 2024

MGMI Calcutta Branch, known for it's innovative ideas and unique activities, apart from organizing workshops / seminars, lecture sessions etc. from time to time on techno-scientific issues, makes conscious effort to promote interaction amongst its members and families. In spite of serious infrastructural and financial constraints and identity crisis faced at times, dedication and enthusiasm of the functionaries over the past decades have proved that Calcutta Branch is one of the most active and vibrant unit of MGMI. Inaugurated in December 1991, the Branch organizes Annual Day Get-together of its members and their families at a tourist's spot / resort in or around Kolkata every year and this has become a flagship event since 1992. Members eagerly look forward to this yearly occasion that provides a unique opportunity for them to meet old friends, fellow colleagues and new acquaintances besides enjoying the day with their families. This year, the 30th Annual Get-together of the members was organized on 7th January 2024 at Green Valley Garden, Dingelpota, South of Boral, 24 Parganas (S), West Bengal. It is a picturesque picnic spot with lush green well manicured lawns, mesmerizing gardens, children's park, play ground, A. C dining hall and a swimming pool for those willing to have a plunge.

Like last year the Executive Committee, considering our social responsibility, decided to entertain a group of special children at the Event. Accordingly, 'Bodhyan', an organization that works for societal integration for special children through sports & games, cultural activity and engagement in productive work through occupational therapy, was contacted. They accepted our invitation to come and take part in the Event. About 40 members from the organization, including special children along with their teachers and guardians joined. They presented a delightful cultural performance, songs, dance and tabla recital that thrilled the entire audience.

Three small luxury coaches were engaged to pick up members & their families in the morning from different parts of Kolkata and outskirts to be dropped back in the evening. Many members came by their own transport. The day started with breakfast consisting of peas kachuri, chholar daal, grilled veg. sandwich, sweets, tea / coffee, midday snacks and beverages were served in-situ, sumptuous lunch (rice, moong daal, mixed vegetable, palak paneer, fish curry, chicken curry, mutton curry, chatni, papad and rosogolla), followed by afternoon tea & biscuits. The Event was interlaced with sports activities – Ladies excelled in 'Putting the Ball in the Basket' and, men attempting to 'Hit the Wicket'. Almost everyone took part in the games joyfully with elders cheering their junior family members to inspire confidence.

The Chairman of the Chapter Dr Ajoy Kumar Moitra while welcoming the participants informed that we are running a lean period but in spite of that we are maintaining this noble activity keeping societal concerns, in mind. He expressed confidence that the Chapter will bounce back strongly, in near future.

Sri Bhaskar Chakrabarty, Hon. General Secretary greeted the members and Bodhyan family and outlined the various activities planned for the Chapter, this year.

The Guests of Honour for the occasion was Shri Janardan Prasad, Director General, Geological Survey of India and Dr B Veera Reddy, President, MGMI and Director Technical, Coal India Limited. Unfortunately, Dr Reddy could not join the Event due to other pressing commitment. Mr and Mrs Prasad were welcomed and along with Senior most member Dr S M Kolay were felicitated with flower bouquet by Dr A K Moitra, Chairman and Sri Bhaskar Chakraborty, Secretary of Calcutta Branch. Mr Prasad was highly delighted to be present on the occasion and spoke about the need for such get-togethers. He appreciated Calcutta Branch for inviting the special children keeping in mind the social responsibility. Mrs. Prasad distributed day-to-day utility gifts to the children including a wheel chair to a 9 year old girl child who is scheduled for Open Heart By-pass Surgery.

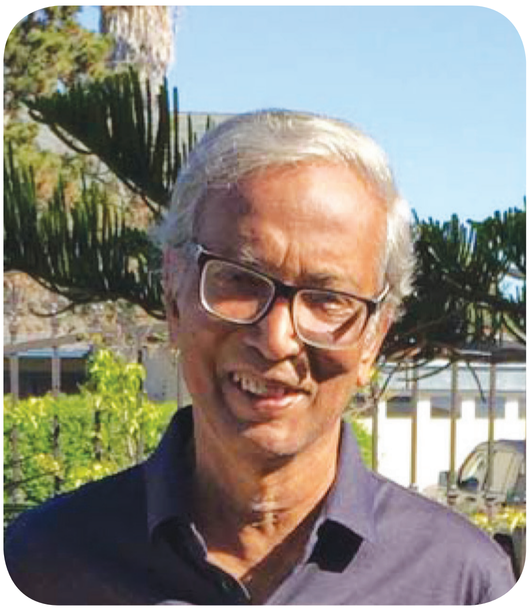
The day long Event was attended by 130 persons comprising members and their families and 40 guests from 'Bodhyan'.

Friends, colleagues, alma maters, professional acquaintances and their families remained engrossed the whole day in 'adda' (chatting).

MGMI Calcutta Branch expresses sincere thanks to all the participating members, especially to Mr. and Mrs. Prasad for making the Event a grand success.

To keep Event alive in one's memory, mementoes were presented to all the participating members.

IN MEMORY OF DR SUNIT KUMAR SARKAR (1937 – 2024)



As engineers at Coal India Limited and SCCL work on increasing production from underground coal mining, we owe much to the leadership of doyens of the prior generation. In particular, Dr Sunit Kumar Sarkar (MMGI, LM – 3272, 1981-82) remained among the most celebrated researchers in longwall mining, both in India and worldwide. This pioneer of longwall mining, a friend to many and a mentor to many more, departed for the heavenly abode on 5th February, 2024. Dr Sarkar served as a Scientist of the Central Mining Research Institute (now known as the Central Institute of Mining & Fuel Research, CIMFR), Dhanbad, for more than three decades.

Born on 16th October, 1937, and raised in the heart of the Raniganj coalfield, Dr S K Sarkar developed a keen interest in coal mining activities early in his life. He completed his School Final Examination from the Board of Secondary Education, West Bengal in 1954, followed by the I.Sc. Examination from Calcutta University in First Division in 1956. He graduated with Honours in Physics from Calcutta University in 1958. Subsequently, he pursued AISM (Mining Engineering) and B. Sc. (Mining) with Honours in 1962 from the Indian School of Mines, Dhanbad.

In 1963, Dr Sarkar joined the Central Mining Research Station (CMRS), Dhanbad, where he dedicated his research and development efforts to strata control in Indian coal mines, particularly in longwall workings. His commitment and diligence in researching ground control in longwall faces in India garnered professional and academic acclaim. He rose to become the Head of the Longwall Research Division at CMRS and earned his Doctorate from Calcutta University in 1973 for his thesis on the development of a methodology for estimating support requirements in Indian longwall faces under different strata conditions.

Throughout his career, Dr S K Sarkar continued to refine his approach in line with advancements in mining methods, drawing from first-hand experiences gained during visits to several European nations including the Federal Republic of Germany, the United Kingdom, France, and Czechoslovakia, where various forms of longwall coal mining were prevalent in diverse geological settings.

In addition to his responsibilities as the Head of the Longwall Research Division, Dr S K Sarkar also took charge of the Flameproof Equipment Testing Laboratory at CMRS. His visit to the UK in 1983 aimed to modernize and upgrade the testing facility for Flame proof (FLP) and intrinsically safe equipment at CMRS, which was later renamed the Central Mining Research Institute (CMRI).

Throughout his service, Dr Sarkar authored four books [Longwall Mining in India (1985); Flameproof Equipment : Design, Construction, Certification, Use, and Maintenance (1988); State of Environment and Development in Indian Coalfield (1996); and Mechanised Longwall Mining: The Indian Experience (1998)], and approximately sixty research papers. He successfully led around fifty technical projects and organized significant workshops and conferences in the field. Dr Sarkar retired from CMRI on the 31st October, 1997.

In addition to being a Life Member of MGMI, Dr. Sarkar represented India in the Working Presidency of the International Society of Mine Surveying and served as the Secretary of the Flame proof and Intrinsic Safety Society of India. He was also a member of several other mining and technical societies, institutions and associations.

Following his retirement, Dr Sarkar authored two books, sharing his unique experiences as a native of a mining area and a mining researcher. The first book, Living Under A Dark Shadow, is in English, while the second, Feere Dekha, is in Bengali.

Dr. Sarkar is survived by his two sons, Subhankar and Priyankar.

GROWTH AND FUTURE PROSPECTS OF THE INDIAN MINERAL SECTOR

Dr Narendra Kumar Nanda, is a distinguished figure in the realm of mining engineering and mineral processing. He is known for leadership skills and his humanitarian nature. He holds a Bachelor's degree in Mining Engineering from ISM Dhanbad, followed by a Master's degree in Reliability Engineering from the same institution, culminating in a Ph.D. in Mineral Processing in 2016. Dr Nanda commenced his illustrious career with NMDC in 1989, where he ascended through the ranks with diligence and expertise, ultimately assuming the mantle of Director (Technical) in December 2008. From 1st January 2012 to 24th May 2012, he held the positions of Chairman and Managing Director at NMDC Limited. With 35 years of experience under his belt, Dr Nanda is renowned for his proficiency in mine operation, development, production, and exploration. Prior to joining NMDC, he garnered invaluable experience in diverse mines of copper and limestone. Among his notable achievements is the pioneering of the MTPA Steel plant at Nagarnar, a testament to his leadership and vision in spearheading significant projects within the public sector. Recognized for his outstanding contributions, Dr Nanda has been honoured with prestigious accolades such as the "Eminent Engineer" award by the Institution of Engineers and the "Mining Engineer of the Year for 2010 – 2011" by the Mining Engineers Association of India, among others. Beyond his professional endeavours, Dr Nanda's leadership extends to various esteemed positions, including Past President of MGMI, President of the Indian Institute of Mineral Engineers (IIME), and Chairman of the Skill Council of Mining Sector (SCMS) promoted by FIMI, underscoring his dedication to nurturing talent and driving industry-wide initiatives. Dr Ajay Kumar Singh, the Honorary Editor of MGMI, deliberated with him on a range of subjects pertinent to the readership of this journal. Excerpts from the conversation are presented here.

Please provide us a glimpse of your career journey in the mineral sector.

Starting my Journey as Deputy Manager at NMDC Limited in 1989, I served in various projects and positions such as Statutory Mines Manager and General Manager-Head of the project at Donimalai. I have been the Director (Technical) at NMDC Limited since 2008 to 2019. I also served as the Chairman and Managing Director at NMDC Limited from January 1, 2012 to May 24, 2012. I played a vital role in laying of foundation to construction of Nagarnar Steel Plant in Chhattisgarh.

I have been Non-Executive Chairman at Legacy Iron Ore Ltd, Australia and Vice Chairman of the JV of NMDC in South Africa. I served as a Director of International Coal Ventures Private Limited (ICVL) having coking coal asset in Mozambique. Other Directorships includes JKMDC Limited, NMDC-CMDC Limited, Krishnapatnam Railway Company Limited. Prior to joining NMDC, I worked with Hindustan Copper Limited and Associated Cement Companies.

I published and presented a number of technical papers during various seminars in India as well as abroad including World Mining Congress. I have done my graduation with B.Tech. (Mining) and M.Tech. from prestigious Indian School of Mines (ISM), Dhanbad and Ph.D in mineral processing from Ballary University, Karnataka.

With experience of about 4 decades, I am a fellow member of the Institution of Engineers (India), a fellow member of the Mining Engineers Association of India and a Council Member of the Mining Engineers Association of India and served as President of your MGMI, the oldest professional body in mineral sector in the country and I feel proud about that. I served as President of Indian Institute of Mineral Engineers (IIME). I made an attempt to record my experience by authoring a book titled **"Application of Technology for Sustainable Mining"** I am happy that I had made somewhere some contribution for the mining and mineral sector in the country.

How can India ensure self-sustenance in the critical minerals necessary for maintaining new infrastructure?

The Geological potential of critical minerals in India is not very high, however in the recent past GSI has developed various blocks for exploration and further production. This method of development will provide the country with a long-term sustainability. Challenges are in developing the process technology and commercially viable product from the low grade multi metal deposits. Recently, Government has started the auction of critical minerals like lithium and will be a boon for the development of the country.

The other way can be tapping resources from the geologically proved deposits globally from where the country can harness both the short-term and medium-term needs.

Further, a vast area of the country is unexplored and has a potential to give a number of mineral assets. Thus, exploration of these areas using new exploration techniques like aerial survey, drone survey, remote sensing etc and developing new technology for beneficiation and processing of these critical minerals for downstream industry can be a game changer for the new infrastructural development in the country.

Could you please discuss any advancements or innovations in sustainable mining technologies that the mining companies in India have embraced to reduce environmental impact and promote resource efficiency?

Several advancements or innovations in sustainable mining technologies include:

- Utilisation of low-grade deposits
- Beneficiation of low-grade ore or lean tailing to higher grade
- Utilising the rejects/ waste to other usage like building/ filling materials, road making, fertiliser, recovery of certain useful metals from slimes etc.
- Use of mechanisation and mechanised transport system like long distance conveyor system to reduce the environmental impact and carbon footprint.
- Use of slurry pipelines to reduce the cost and carbon footprint.
- Utilisation of mine dumps and mined out areas for solar power generation.
- Mining of total ore body and stacking and blending of various grades of ore to ensure total utilisation of ore.
- Use of electric operated HEMMs, especially dumpers started in Indian Mines.
- In order to automate the operations,

companies have adopted Mine Transport and Surveillance System, OITDS- Operator independent truck dispatch System etc.

How the companies ensure responsible sourcing of raw materials for metal and mineral production, particularly in terms of ethical labour practices and environmental stewardship?

The sourcing of raw material is from small to large mines and metal production is generally from the factories and process plants. With the advent of contractual mining the labour practices are at times compromised with the skill and working hours. The regulatory framework provides for the checks and balances and with a stricter adherence to law the shortcomings can be addressed.

The labour practices and welfare are in general above par in the public and established private sectors. Only a slighter caution is required in ensuring a strict compliance of the rules in case of contractual engagements.

Mines Act and related regulations keep a watch on adherence to the norms and welfare of the work force in mines. Apart from above, companies are working on the idea of comprehensive development of local area and spending a lot on Corporate Social Responsibility.

Government has also come with a special fund with the name of District Mineral Fund collected from miners for the local development.

What strategies the mining companies in India employ to minimise the environmental footprint of its material processing operations, such as reducing energy consumption or optimising water usage?

Selection of right technology and method for beneficiation, which suits the type and grade of the ore, as well as the environmental conditions and regulations of the site. For example- gravity separation uses the difference in density and size of the minerals to separate them, which requires less water and produces less tailings. Other potential interventions include use of more green power in beneficiation like solar power, hydro power etc, adoption of energy efficient technology, equipment and system/ processes like variable speed drives, high-pressure grinding rolls, and pre-concentration techniques, striving for net-zero emission and ensuring zero discharge of water. Furthermore, companies must implement water recycling and reuse systems, such as thickeners, filters, and ponds, that recover and treat the water from the process. This will reduce the use of water. Design and operate tailings storage facilities that are safe, stable, and compliant with the standards and guidelines and utilising lean tailing for making of bricks, tiles, building materials etc. can also help reduce the environmental impact.

What measures are in place to ensure transparency and accountability in mining company's supply chain, especially regarding the traceability of raw materials and compliance with environmental regulations?

In order to trace the raw material, mining companies has to file monthly return to Indian Bureau of Mines (IBM) related to production of minerals. Further, IBM officials conduct audits to check the mines and processes and give their observation for compliance. Additionally, mines are now under surveillance through satellites by government agencies to avoid any illegal mining.

Companies conduct Environmental Impact Assessment before applying for Environment clearances for mining operation. The authorities give certain conditions while approval which needs to be complied for starting and operating the mines. Agencies like Environment and Forest also visit mines for compliances related to Environment. In coal mining sector the Ministry of coal has issued guidelines for mine planning which encompasses the basic principle of sustainability and Government has gone one step further by making it mandatory to get accreditation from NABET to prepare mine plan.

How do you assess and mitigate the potential impacts of climate change on mining operations and supply chain, and what adaptation strategies have been implemented?

Mining operating and beneficiation requires a lot of energy input, which mostly causes carbon emission. Rising demand for more minerals will necessarily be associated with increases in energy needs. In order to avoid deepening the challenges related to climate change, companies should make a sustainable energy plan with focus on renewable energy and use of technology to reduce consumption. Each company should conduct the carbon impact assessment from their operation including Scope 1, 2 and 3 emissions and should make a target to reduce carbon footprint.

Could you please share insights into the role of innovation and research in driving sustainability improvements in the mining and materials industry, and any notable projects or partnerships in this regard?

Mining companies are doing a lot of R&D for utilisation of banded hematite quartzite or BHQ (a waste material) and beneficiate to use such ore. They also collaborate with international agencies to develop technology for dry beneficiation etc. Institutions like ISM, Dhanbad, IIT Kharagpur, NITs are doing a number of research in the field of mining.

What specific goals or targets should mining companies set to measure progress towards sustainability, and how are these targets tracked and reported?

The metals and mining industry accounts for approximately 4% to 7% of worldwide greenhouse gas emissions. Apart from government, companies should be self-regulated and should set a target of carbon neutral by 2050. Government may come up with policy of carbon tax to mitigate the problem. Carbon emission as well as impact on environment by mining activity should be mandatorily reported along with company's annual reports for information to the agencies as well as common public.

How do the mining companies address challenges related to responsible waste management and mine closure, ensuring long-term environmental and social legacies are positive?

There are regulations in place to deposit a certain amount of fund right from beginning of operation, for mine closure. These funds can be utilised judiciously for mine closure. Mine closure should also take care of livelihood of local community, and it should include a plan to create a system of revenue generation for local community after closure of the mine. This community were dependent on these mines while in operation. Kudremukh Iron ore mine is a classic example of mine closure.

Looking ahead, what do you see as the key opportunities and priorities for advancing sustainability in the metals, minerals, and materials sector, and how are the mining companies positioned to lead in these areas?

Mining companies create good revenue extracting valuable minerals, but often misses the surrounding communities to include them as partners in their work and the environment. Regulating these activities mainly depends on national frameworks and policies, but implementing good practices remains challenging. In order to shift to "sustainable mining," governments and companies must recognise the social impacts of mining and enact laws and regulations that require community consultation throughout the life of a mine and create an atmosphere of ease of work for the miner.

There is a need for more innovative solutions to optimise the mining industry's benefits and reduce its negative social and environmental impacts. Public-private partnerships is one of such option to reduce the impact.

Environmental, health, and safety issues had diminished mining's social license to operate in many communities. The solution is that mining business model should be a partnership development model for all stakeholders and work together to achieve these goals. Most mining companies now have some form of corporate social responsibility approach through their activities, or are required to implement environmental, social, and governance principles in the company to mitigate.

In collaboration with academic researchers, the companies can develop technological solutions for the mining sector to meet the goals defined for sustainable development. The key to any sustainable development intervention is to consult with those who can benefit most, the immediate communities. Without addressing their real concerns, meeting the goals of sustainable development is not achieved.

I am extremely thankful to MGMI and to you as the Editor of the journal for giving me the opportunity to express my thoughts for the appreciation of the dear readers of the MGMI journal. I wish the journal to flourish under the able guidance of the MGMI council and it's Editor.

SUSTAINABLE SOURCING OF CRITICAL METALS : FUTURE DIRECTIONS

Arun Kumar Shukla

Abstract

Sustainable sourcing of critical metals and minerals is important for achieving the net-zero emissions targets and is the biggest challenge as well. With the ambitious decarbonization targets taken worldwide by the countries, demand for the metals and minerals like copper, nickel, lithium, cobalt, graphite, rare earth elements (REEs), which are the critical raw materials for the low-carbon reduction technologies, is increasing immensely. However, a demand-supply gap is anticipated. Limited occurrences, insufficient mine production, geographic concentration, geopolitical factors, race to secure supply chain, increasing trend of protectionism and resource nationalism are causing supply risks for the critical raw materials and market volatility. India has limited potential for these critical metals and minerals, as on date. Therefore, mining alone may not fulfil the demand of these critical metals to develop a robust domestic downstream market to achieve ambitious targets of decarbonization. To achieve self-reliance and for sustainable sourcing of the critical metals a composite approach is required, by enhanced exploration to augment domestic resources base and promoting mining, overseas sourcing, optimizing processing technology, recycling and extraction of critical minerals from mine wastes or tailings as well as exploring the unconventional sources like deep sea mining.

Introduction

To achieve net-zero emissions targets, ambitious decarbonization goals have been taken by the governments around the world. Fundamental technology shifts across industries will be required at an unprecedented speed to achieve the net-zero emissions targets, by adopting widespread electrification, and replacement of hydrocarbons with renewable power sources. Low-carbon reduction technologies and energy solutions are dependent on minerals and metals like copper, nickel, lithium, cobalt, graphite and rare earth elements (REEs). Predictions show demand of these critical raw materials for the low-carbon reduction technologies and energy solutions is set to witness a significant increase over the next decades as clean energy technologies and their supporting infrastructure, ranging from wind turbines and EV batteries to CO_2 pipelines and power grids, use more critical mineral components than the conventional energy infrastructure. According to the International Energy Agency (IEA)'s Announced Pledges Scenario, demand for these critical minerals and metals will grow more than two-fold by 2030 (IEA, Critical Minerals Market Review 2023). However, prediction also shows the possibility of supply deficiency of these critical raw materials with respect to the rising demand. The demand-supply gap would lead to significant price spikes and

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volatility across minerals, which in turn would make the key technologies more expensive. Therefore, sustainable sourcing of critical metals is going to be the biggest challenge for achieving the decarbonization goals.

Increasing demand trends for the critical raw materials for electrification

Researchers predicted that demand for critical minerals for clean energy technologies is set to increase by more than 2 times and 3.5 times higher by 2030 compared with today, in the Announced Pledges Scenario (APS) and Net Zero Emissions by 2050 (NZE) Scenarios, respectively (Global EV Outlook 2023, published by IEA). Predicted Supply-demand gap will be about 8% for copper, about 6% for Nickel, about 6% for Lithium in an Announced Pledges Scenario of IEA (World Economic Forum, December 2023).

As per the database of IEA published in July 2023, with respect to 2022, demand of copper will increase about 1.24 times by 2030 and about 1.54 times by 2050, demand of cobalt will increase about 1.56 times by 2030 and about 2.89 times by 2050, demand of nickel will increase about 1.54 times by 2030 and about 2.22 times by 2050 from the demand of 2022 and demand of lithium will increase about 3.44 times by 2030 and about 9.23 times by 2050.

Demand Trends for Critical Metals (Based on IEA Database published in July 2023)

Clean energy technologies	Copper (in kt)			Cobalt (in kt)			Nickel (in kt)			Lithium (in kt)		
	2022	**2030**	**2050**	**2022**	**2030**	**2050**	**2022**	**2030**	**2050**	**2022**	**2030**	**2050**
Electric Network	4342	7440	8887	65	113	296						
Solar	732	1177	1811									
Electric Vehicle	373	1592	3307				326	1498	3273	70	350	1040
Wind	450	885	1107				41	72	88			
Grid Battery Storage	23	130	444	14	9			30	61	4	19	50
Other low emission power generation	91	141	160				88	486	461			
Hydrogen Technologies								45				
Others	19766	20706	24023	103	163	229	2477	2398	2625	57	83	120
Total	**25776**	**32070**	**39740**	**182**	**284**	**525**	**2932**	**4529**	**6507**	**131**	**451**	**1209**

It is also predicted that while at present clean energy technologies contribute about 23% of the total demand for copper, by 2030 it will be 35% and by 2050 it will reach 39%. For Cobalt currently it is about 43% and by 2050 it will reach 56% and for Nickel currently it is about 16% and by 2030 it will reach 47% and by 2050 it will be 60%. Whereas for Lithium currently it is about 57% and by 2030 it will reach 82% and by 2050 it will be 90%.

Copper is used in all clean energy technologies, two largest energy transition demand drivers being the grids and electric vehicles. It has considerable usage in non-energy sectors as well. Demand growth for copper is also driven by industrialization and economic development of countries. It is reported that Electrification is likely to increase annual copper demand to 36.6 million metric tons by 2031, against projected supply of 30.1 million metric tons (McKinsey, February 2024). The supply projections are estimated based on restarts, certain or probable projects, and recycled production.

India has also announced its ambitious national goals for 2030 at the COP 26 UN Climate Change Conference, held in November 2023. This includes increasing non-fossil energy capacity to 500 GW by 2030, obtaining 50% of electricity needs from renewable sources by 2030, limiting projected carbon emissions by one billion tonnes, and lowering the carbon intensity of its economy by less than 45% by 2030.

Lithium-ion battery being the key component used in electric vehicles to store renewable energy, growth from 2.9 giga-watt hour (GWh) in 2018 to about 132 GWh by 2030 (at a CAGR of 35.5%) was predicted for the lithium-ion battery industry in India in a report published by Niti Aayog in February 2022. The re-cycling market of these batteries was estimated to be nearly 22-23 GWh in 2030. As per the report published by Niti Aayog in June 2023, India's advance chemistry cell manufacturing industry will need ~193 thousand tons/annum of Cathode Active Material (contains Lithium, Nickel, Cobalt Manganese, Iron, Phosphorus etc.) to produce ~100 GWh /annum of batteries by 2030, along with ~41 thousand tons/annum of copper, ~ 41 thousand tons/annum of Aluminum, ~98 thousand tons/annum of Graphite.

As reported, the world is currently on a 2.5 degree Celsius warming trajectory and transformative action is needed at this stage to achieve the goal of Net Zero Emission scenario by 2050 as per the Paris Agreement of 2015 (Wood Mackenzie's 2023 Energy Transition Outlook report). Rapid adoption of low-carbon technologies is needed globally, at an enormous scale.

Sourcing of the Critical Metals

Sourcing from Mines : Global Status

While sustainable sourcing of metals and minerals like copper, nickel, cobalt, lithium, graphite, REE, are crucial for energy transition, due to the inherent geological characteristics, these metals and minerals have limited availability on the earth's crust and show high geographical concentration in terms of occurrences of their ore deposits. Production of the refined metals is also concentrated in few countries.

For copper, 57 % of the world's total production in 2022 was only from the 3 countries : China, Chile, and Democratic Republic of Congo. 52% of the World's total copper ore reserve is restricted in 5 countries : Chile, Australia, Peru, Russia & Mexico. Copper ore is predominantly derived from porphyry copper deposits, with lesser but significant contributions from massive sulfide, skarn, and other types of deposits. The porphyry copper deposits are typically large (commonly hundreds of million tonnes) and of low grade (commonly < 1% Cu). The average grade of copper ore is near about 04 to 05% as reported.

About 68 % of world's total production of Cobalt in 2022 was from Congo (Kinshasa) followed by Australia with 5%, while both the countries together hold about 66% of world's total Cobalt reserves. Identified world terrestrial cobalt resources are about 25 million tons in terms of metal. Majority of these resources are in sediment-hosted stratiform copper deposits in Democratic Republic of Congo and Zambia; nickel-bearing laterite deposits are in Australia and nearby island countries and Cuba. Also, magmatic nickel-copper sulfide deposits hosted in mafic and ultramafic rocks in Australia, Canada, Russia, and the United States are reported. The cobalt grade typically varies between 0.04% and 0.08%. Apart from the above, more than 120 million tons of cobalt resources have been identified in polymetallic nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans.

For Nickel about 48% production in 2022 was from Indonesia, followed by Philippines with contribution of about 10% and Russia about 7%, where as about 58% of the total reserves is contained by 3 countries : Australia, Brazil and Indonesia. Identified land-based resources averaging approximately 0.5% nickel or greater contain at least 300 million tons of nickel in terms of metal, with about 60% in laterites and 40% in sulfide deposits. Extensive nickel resources are also found in manganese crusts and nodules on the ocean floor.

For Lithium, 96% production in 2022 was from 4 countries : Australia, Chile, China, & Argentina, contributing about 47%, 30%, 15% and 5% respectively. About 52% of the World's total Lithium Resources is restricted in three countries: Bolivia, Argentina & Chile, known as Lithium Triangle; Australia and China contain another 15%. There are three main sources of lithium globally : brines, pegmatites and clays. Around 51% of current production is from lithium brines with the remaining 49% from pegmatites. There is potential for lithium-bearing clays as a lithium source, but no commercial production has been reported yet.

However, with the enhanced focus on exploration world wide, boosted investment in critical mineral exploration as well as advancement in exploration technologies, many new discoveries are being reported from various geographical locations, which gradually is relaxing the monopoly in mining of critical minerals.

Production of refined metals or minerals shows more skewed distribution, with the majority production coming from a limited number of countries. This is due to various reasons, specific to the countries, like Government policies, technological advancement, infrastructure, socio-political situation, ease of doing business apart from availability and nature of the ore deposits.

China holds a dominant position in critical mineral processing and manufacturing. The country refines 68% of the world's cobalt, 65% of nickel, and 60% of lithium of the grade needed for electric vehicle batteries, also accounts for 85-90% of global rare earth element mine-to-metal refining. Further Seventy-five percent of all batteries and a majority of electric vehicles are made in China.

Challenges for Sustainable sourcing of raw materials

Geographic concentration of the occurrence and production of the critical raw materials may raise supply risks, triggered by various geopolitical factors. The highly fluctuating metal market conditions, resulted mostly due to disrupted supply chain, have been observed during COVID-19 pandemic, Russia's full-scale invasion of Ukraine, and ongoing tensions between the US and China.

As global demand for these critical raw materials for energy transition has skyrocketed, the race to secure supply of these critical minerals has become more pronounced in the global arena. The increasing trend of protectionism and resource nationalism is being seen around the world and impacting the critical mineral supply chains.

While demand for the critical metals is increasing enormously, the shallow and high-grade ore deposits are depleting fast. Exploration, mining as well as processing is becoming more and more complex and demanding a high skill set as well as high CAPEX investments. Study shows, in the year 1900 the average of copper contained in the rocks was approximately 4%, while currently, the grades are close to 0.5% Cu (Mudd, 2009; Toro, 2020).

Many of the major open cast mines are converted or being converted into underground mines like Freeport McMoRan Copper & Gold's Grasberg mine in Papua, Indonesia, Codelco's Chuquicamata mine, Chile, South Africa's Palabora mining with the increasing depth of mining.

Specially for the metals like copper, nickel, cobalt etc., ore deposits, which mostly show complex and highly varying characteristics controlled by their genesis, irregular shapes, limited strike length and width with considerable depth continuation, along with complex polymetallic mineralogical assemblages, mining and processing is becoming more tough and complex with increasing depth and requirement of higher production.

Mining projects contain multiple inter dependent components, including discovery & exploration, mine planning and designing, process designing, feasibility studies, obtaining licenses and statutory permitting regarding Environment, Forest, Wild-life, mine development & construction of plants and infrastructure and Production, as well as requires socio-environmental engagement. Therefore long lead times between exploration and mineral production are required and that cannot easily be compressed. A study carried out by S & P Global Market Intelligence in June 2023 on 127 precious and base metals mines, that began production between 2002 and 2023 and were discovered from 1980 onward, has shown the average lead time of 15.7 years from discovery to commercial production, with a range of six to 32 years.

Status of Critical Metal ore Resources and Production in India

World's total copper ore reserve is 890 Million tonnes, and identified resources is 2100 Million Tonnes, while in India the established copper ore reserves is 2.16 million tonnes, out of the total copper resources of 12.20 million tonnes in terms of copper metal i.e., India contributes 0.24% and 0.6% of world's total reserves and resources respectively (IBM Yearbook, 2021). Copper ore in India has an average copper content of around 1%. The copper ore and concentrate produced in India cater only about 4.5 % of country's total requirement at present, from the 5 operating mines of the State-owned company Hindustan Copper Limited. The company is in the process of capacity expansion in phases, with an aim of 3 to 4 times production enhancement in the initial phase.

For Cobalt, ore resource of ~ 45 Million Tonnes and for Nickel ore resource of 42 Million Tonnes @>0.9% Ni, 94 MT @ 0.5-0.9% Ni and 53 MT < 0.5% Ni, are reported (IBM Yearbook, 2021). There is no production of Nickel and Cobalt from mines in India as on date. Although some recent break through discoveries have been made for Lithium ore deposits in India, and number of exploration projects for Lithium are in progress, as on date India has no estimated reserve for Lithium. The country is primarily dependent on imports for copper, nickel, cobalt, lithium and a number of other critical and strategic minerals.

However, for a thriving domestic lithium-ion battery (LIB) manufacturing industry as well as achieving the goal of decarbonization, India will need resilient supply chains of critical minerals and raw materials.

Sourcing from non-conventional Sources

While mining will remain the primary source of the metals, the supply of commodities such as copper, nickel, lithium, cobalt and rare earth elements (REEs) from this conventional source alone may not be sufficient to meet the demand of the year 2030 and beyond.

As a secondary source, recycling of scraps, for extraction of metals, specially, copper has significant potential, as copper can be recycled repeatedly without any loss of material properties. There is also no difference in the quality of recycled copper (secondary production) and mined copper (primary production). Recycling of end-of-life batteries etc. could become a potential alternative to mining for a large portion of material requirements in the coming years. The World Bank estimates that recycling rates for end-of-life batteries may increase significantly by 2050, which decreases the need for newly mined minerals by around one-quarter for copper, nickel and lithium and by about 15% for cobalt. However, by 2030, there will not be enough of these materials in circulation to make recycling a prospective alternative source. The IEA estimates that by 2040, recycled copper, lithium, nickel, and cobalt from spent batteries alone could provide 10% these minerals. However, there is an urgent need for developing SoPs and guidelines to manage the adverse effect on the environment.

Extraction of critical metals from mine tailings is being focused worldwide. Research projects are being taken up to extract necessary minerals from coal waste or hard rock mine tailings. Recovering critical metals like lithium, cobalt, rare earth elements from abandoned mine tailings has recently gained increased attention worldwide, through tailor-made hydrometallurgical processes such as solvent extraction, acid leaching as well as bio-hydrometallurgical processes. However, these methods can be resource intensive, costly and complex, and can often lead to adverse environmental impacts. Bioleaching methods are coming up as an environment friendly tool for effective recovery of these elements from mine tailings.

Offshore mining for critical minerals is coming up as an alternative source to maintain sustainable sourcing of the critical raw materials in the coming days.

Deep sea mining is being evaluated as an unconventional and future source for metals like copper, nickel, lithium, cobalt and rare earth elements. Areas that are over 200m deep are considered as "deep-sea" (Danovaro *et al.*, 2017). These deep-sea areas cover 360 million km^2 of the Earth's surface and represent 95% of the global biosphere in terms of the habitable volume (Miller *et al.*, 2018). The estimated mean and median ocean depth are 3897 and 3441m. Depths above 3000m represent 75.3% of the oceans, where 85% remain unexplored (Stewart & Jamieson, 2019).

In the deep sea, minerals are found as marine nodules, ferromanganese crusts, and massive polymetallic sulphides (Schriever & Thiel, 2013). Ferromanganese crusts and nodules are formed by direct precipitation in seawater, along the flat parts and on the flanks of seamounts, where ocean currents prevent sedimentation (Konstantinova *et al.*, 2017). These deposits are located in all oceans around the world. While polymetallic sulphides are found in a wide variety of volcanic and tectonic environments like oceanic ridge system, at depths that vary between 3700–1500m, formed when seawater interacts with the heat of magma in the subsoil region (Herzig & Hannington, 1995, M. Hannington *et al.*, 2011).

These deposits differ from each other, mainly in their physical and chemical properties, formation, metal content, geographic distribution, and calls for tailormade extraction technologies, as well as requirements for dealing with environmental and social aspects associated with their extraction.

While the grade of the terrestrial deposits is continuously decreasing, sub-sea polymetallic sulphide deposits have grades between 1 and 12% Cu, manganese nodules also contain grades of 1% Cu (James R. Hein *et al.*, 2013). When depth of mining for metals like copper, zinc have reached well beyond 1000m and number of the mines have reached even depth above 3000m, the deposits of marine nodules and ferromanganese crusts forms two-dimensional layers on the seabed, massive polymetallic sulphides form three-dimensional structures with tens of meters thickness, with almost no overburden materials (Hein & Koschin sky, 2013; Hein *et al.*, 2013). Researchers reported that considerable reserves of cobalt, nickel, manganese and rare earth are found in submarine deposits (Pak *et al.*, 2019).

However, there are challenges due to its great depth, distance, and extent, exploration and mapping is a highly challenging process, only a small fraction of the ocean floor has been bathymetrically mapped till date (Mayer *et al.*, 2018; Stewart & Jamieson, 2019).

International seabed exploration is being monitored by the UN's International Seabed Authority (ISA). ISA issues permits to explore deep-sea mining in international waters. ISA as on date has entered into 31 contracts for the exploration for polymetallic nodules (PMN), polymetallic sulphides (PMS) and cobalt-rich ferromanganese crusts (CFC) in the deep seabed, with 22 contractors. Nineteen of these contracts are for the exploration for polymetallic nodules in the Clarion-Clipperton Fracture Zone, Central Indian Ocean Basin and Western Pacific Ocean; the Clarion-Clipperton Zone in the Pacific Ocean alone hosts 17 exploration contracts being the most promising area.

Another 7 contracts for exploration for polymetallic sulphides are there in the Southwest Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and 5 contracts are there for exploration for cobalt-rich crusts in the Western Pacific Ocean.

The Government of India, through Ministry of Earth Sciences, currently holds two contracts for exploration in the Indian Ocean. The first one was signed in 2002 for exploration for polymetallic nodules in the Central Indian Ocean Basin and the second contract signed in 2016 for the exploration of polymetallic sulphides in the Indian Ocean Ridge. Two new applications have also been submitted to the International Seabed Authority (ISA) during January 2024 for exploration in the international seabed area of the Indian Ocean for polymetallic sulphides in the Indian Ocean Ridge (Carlsberg Ridge) and cobalt-rich ferromanganese crusts of the Afanasy-Nikitin Seamount in the Central Indian Ocean. Preliminary estimates indicate that 380 Million Metric Tonnes (MMT) of Polymetallic Nodules comprising of copper, Nickel, Cobalt and Manganese are available within an allocated area of 75000 sq. km to the Government of India for exploration in Central Indian Ocean Basin. The polymetallic sulphides are expected to contain rare earth minerals including gold and silver.

As reported ISA is in the process of finalizing regulations that will dictate whether and how countries could pursue deep-sea mining in international waters, decision is expected by 2025. More research is ongoing to determine the possible ecological impacts of deep-sea mining.

Deep-sea mining aims to retrieve valuable mineral deposits found. Recent advancements in technology have made it possible to mine on the ocean's floor, hundreds or even thousands of meters below the surface, by sending vehicles down designed to harvest mineral deposits from the seafloor. These suitably designed Mining vehicles would collect mineral deposits from the surface of the seabed, along with the top layers of sediment and transfer them to a surface vessel for processing.

While regulations for deep-sea mining in international waters are under preparation by ISA, countries are focusing on deep-sea mining projects in their "Exclusive Economic Zones" (EEZs). However, as reported, quality of the mineral deposits found in countries' EEZs are not as good as the deposits found in the vast seafloor abyssal plains in international waters.

Geological Survey of India (GSI) under the Ministry of Mines has delineated prospective offshore areas within Exclusive Economic Zone (EEZ) of India for marine mineral resources like lime mud, heavy mineral placers [ilmenite, monazite, rutile, sillimanite, garnet, zircon], and construction sand. As reported GSI has identified blocks in the exclusive economic zone of India, i.e., beyond territorial water (12 nautical miles) and within 200 nautical miles from the baseline, for the minerals lime-mud & polymetallic nodules which can be taken up for auctions to take up exploration & exploitation. Ministry of Mines is working on the necessary amendments in the offshore areas mineral (Development & Regulation) Act, 2002 and developing standard operating procedures to be followed if a private sector bidder wins the block for exploration, as reported.

Concluding remarks

Achieving the goal of decarbonization and Net zero emissionis dependent on sustainable and resilient sourcing of the raw materials. Diversification of supply chain and self-reliance are the important factors to aim at, to combat the market volatility, required for maintaining manufacturing costs and competitiveness. For India, at present dependency on import is 100% for Lithium, Cobalt, Nickel, more than 95% for copper concentrate and about 50% for copper metal. As on date India has meagre resource base for these minerals, though considering the geological resemblance with the resource rich countries like Australia, South Africa, there are possibilities of new discoveries with enhanced focus on exploration. With the recent amendments of mining regulation of the country, and access of private sectors & junior miners in exploration of critical minerals, there is a possibility of improvement of domestic critical mineral inventory. However, considering the standard timeline of exploration and mining projects, completion of exploration and development of new mines may take a decade or more. Therefore, the need for sustainable sourcing of critical minerals from overseas though acquisition of mineral assets or mining projects as well as long term investments like offtake arrangements, cannot be ignored. Short-term and long-term planning for sourcing of the critical minerals based on mapping of demand in the domestic downstream industry for the individual raw materials as well as assessment of scope of business in global market is important. Government of India is putting emphasis on Circular economy which ensures sustainable growth over period and works as a tool to tackle climate change. Optimum utilization of the metal scrap will also give a fillip towards the sustainable sourcing of critical metals in coming years.

Thus, a composite approach for sustainable sourcing of raw materials has to be adopted considering the conventional primary and secondary sources as well as non-conventional sources. Though there will be uncertainties, as the potential of the non-conventional sources are yet to be proven, also, they have their own gestation time. Further, the uncertainties are also there for the demand trends of certain minerals, as possibilities of change in technology cannot be ignored, e.g., shifting from nickel manganese cobalt oxides (NMC) batteries to lithium iron phosphate (LFP) batteries during 2015 to 2022; emerging technologies such as sodium-ion batteries which may reduce the demand for Lithium and Cobalt with cheaper and more abundant options. Integration of industry, academia and enhanced focus on research and development to improve exploration, mining, beneficiation and processing technology, optimized extraction of the critical minerals from low grade ore, wastes, tailings etc. and developing unconventional sources is the key to the sustainable future. It cannot be ignored that metals and mining industry itself accounts for approximately 4% to 7% of worldwide greenhouse gas emissions, therefore developing secondary and non-conventional sources to replace mining as much as possible will be beneficial for achieving green economy.

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A JOURNEY THROUGH THE PAST AND FUTURE OF UNDERGROUND GOLD MINING IN INDIA

Dr Prabhakar Sangurmath

Introduction

The history of mineral mining in India dates to the days of the Harappa civilization. The wide availability of minerals in the form of abundant rich reserves and the Eco-Geological conditions make it very conductive for the growth and development of the mining sector in India.

Indian Mining industry makes a major contribution to the economy and to the wellbeing of the society as a whole. The country's mineral industry represents a unique mix of very small, medium to large mines. Currently there are over 440 coal mines, 50 oil and gas projects and a large no. of non-coal mines with a record of 15,757 reporting mines. Total workforce of the mining industry in India consists of about one million.

India produces as many as 95 minerals, including 4 fuel, 3 atomic, 10 metallic, 23 non-metallic, and 55 minor minerals (including building and other materials). There continues to be a huge demand for minerals due to rapid urbanization and growth in the manufacturing sector in India. India holds a dominant position in the global production of many minerals.

As per the first advance estimates national income for 2022-23 released by the National Statistical Office, Ministry of Statistics and Program Implementation, the 1st Advance Estimates of Gross Value Added (GVA) of mining and quarrying sector during 2022-23 at 2011-12 prices is 3,35,810 crore, which shows a growth of 2.39% as compared to provisional Estimates of GVA during 2020-21 at Rs 3,27,984 Crore. The mining sector contributes nearly 2.84 percent to India's GDP.

India's ranking in 2020 in the world production was 2nd in Steel (crude/liquid), 3rd in Zinc (slabs) & Aluminium (primary); 4th in Chromite and Iron ore; 5th in Manganese ore; 6th in Bauxite; 7th in Copper (refined); 15th in apatite & rock phosphate; and 17th in Magnesite.

India is indeed blessed with abundant natural resources that have provided the foundation for the present living standards through the development of mining and resource industry. The positive effects of mining on the economy have been significant & long lasting. There are large opportunities for direct and indirect employment. Benefits in remote areas, like better roads, sewerage systems, hospitals, schools, reasonable job opportunities for local people etc. comes from the impact of Mining. The positive effects of mining on economy will also continue to spread through its technology-driven practices and increased safety and productivity measures.

Exploration : Key to Resource Development

Mineral exploration is at the heart of mining. It is a scientific-knowledge and technology-driven

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process involving high risk capital. Country's mineral wealth is yet to be fully explored, assessed, and extracted for enhancing its contribution to the country's GDP as well as Socio-Economic development of remote and tribal areas.

Amidst the vast expanse of the Earth's crust there lies an extensive reserve of minerals, each harbouring its own unique narrative. From the depths where gold and diamonds gleam, to the intricate veins of copper, lead, zinc, and finally, to the deposits where iron ore and coal exist for extraction, India's geological riches are plentiful. The occurrences of significant minerals in India, along with their resources, reserves, and the percentage of reserves to resources, are presented in Table 1.

Table 1 : OGP, resources, reserves, and % of reserves to resources for significant minerals in India

	OGP (sq.km)	Total resources (million tonnes)	Reserves (million tonnes)	% of reserves to resources
Deep seated minerals				
Gold	1,43,529	518.234	23.72	4.58%
Diamond	3,00,000	31,723,991*	847.559*	2.67%
Base metals				
Copper ore	1,92,245	1,660,87	163.89	9.87%
Lead and Zinc ore		766.49	103.28	13.47%
Surficial minerals				
Iron ore	22,171	35,285	6,411	18.17%
Coal	60,215	361,411	187,105	51.77%
Source : Geological Survey of India and Indian Bureau of Mines: *: carats				

Future Demand for Metals :

Most of the things which are required for a sustainable future- wind turbines, solar panels, electric vehicles- are metals' intensive. Being elements of nature, metals have the potential to be recycled almost indefinitely. For example, around 2/3rd of aluminium produced is still in use in some form today. Further, 2/3rd of the copper produced since 1900 is still in productive use (FIMI-2024).

However, recycling alone will not provide enough materials to meet demand. According to studies, across commodities, fresh supply needs to grow between two-fold and twenty-fold in the next 30 years even with improved recycling rate. It is estimated that by 2040 there could be 20-fold increase in demand for nickel and cobalt to meet the needs of an increasingly electrified world. Copper demand is expected to double by 2035. It has been reckoned that reaching net Zero by 2050 will require an estimated 3 billion tonnes of metals as well as significant investments of roughly US 9.2 trillion each year (FIMI-2024).

Gold Mining and Exploration in India

Amongst all metals found in the earth's crust, gold is the most precious one. Gold not only symbolizes individual's prosperity, but also represents the strength of a Nation.

Mining and Agriculture have been and remain, for the foreseeable future, the two basic industries or occupations on which all other human activities eventually depend. For the gold, man has retained a curious fascination for more than 5000 years, undoubtedly promoted by its great natural beauty and universal durability. The gold continues to represent stability and relatively constant intrinsic value over a long period. The yellow metal has caused some of the greatest human migration, and has cursed and blessed. India is the leading gold consumer in the world. Table 2 presents India's gold resources, encompassing both primary and secondary gold ore deposits, as well as primary and secondary gold metal resources.

Table 2 : Gold Ore Reserves of India as on 1.4.2020

(Source : Indian Mineral Yearbook 2022, IBM)

Gold Ore (Million tonnes)	Primary	518.23
	Secondary	26.12
Metal (tonnes)	Primary	607.26
	Secondary	5.86

Gold occurs in a variety of geological settings. About 92.76 tonnes of gold metal is categorized as reserves (economically mineable) and resources of gold is about 514.50 tonnes of gold metal identified by GSI, MECL, HGML and other agencies. These reserves and resources exist in deposits and prospects spread over 11 different states of the country. However, these resources await upgradation by substantial deep diamond drilling, exploratory mining, and feasibility studies before they reach the status of mineable reserves.

Gold Mining in India

Mining for gold in India existed in pre and post Ashokan times. Rediscovery of various gold fields took place after the reopening of the Kolar Gold Fields in 1880.

The Bharat Gold Mines Ltd (BGML) from KGF of Karnataka has a continuous glorious gold production almost 120 years, has produced about 800 tonnes of gold and ranked as giant gold field of world class. Considering the deep mining (3 km deep), economics, administrative problems, BGML closed its operations from March 2001.

The Kunder Kocha Gold Mine is about 50 Km south of Jamshedpur -Tatanagar. The mining was taken up by M/s Man Mohan Mineral Industries Pvt Ltd from 2003-2019. Now no production and mining activity is reported.

Presently, the primary gold production comes essentially from Karnataka i.e. Hutti Gold Mines Co Ltd (HGML) (A Govt of Karnataka Enterprise), which produce nearly 1.7 tonnes of gold per annum. The Hutti Underground Gold Mine is the oldest metal mine in the world amongst the existing mines. HGML has produced about 98 tonnes of gold from 1947 to 2024. HGML has gold reserves of around 18.87 millon tonnes @ 4.10 g/t in its mining lease hold areas. The present depth of Hutti underground gold mine is 960 meters and it can be mined upto 3 km depth as per geophysical exploration. The HGML, having its corporate office at Bangalore operates two units, The Hutti Gold Unit (HGU) in Raichur district and Chitradurga Gold Unit (CGU) in Chitradurga district, Karnataka. HGML is active in Exploration, Mining and Metallurgy of Gold/Copper/Sand deposits of Karnataka. HGML is built upon for long term vision and clear mission. It is one of the most vibrant, self-reliant, a financially viable, growth oriented and human organisations.

Apart from these primary sources of gold, it was also produced in small quantities as a by-product during the refining of copper by Hindustan Copper Ltd (HCL), a Govt. of India Enterprise.

Demand and Supply

The demand for Gold in India is not only the highest in the world but also one of the fastest growing markets. It is projected, that the gold consumption in India may reach about 1200 tonnes. The domestic mine supply is around 1.7 tonnes/year.

India house holds about 20,000 tonnes of gold, which is stated to be the largest stock of gold in the world and imported about 930 tonnes of gold. Jewellery accounted for major consumption of gold i.e. 85%, followed by electronics 6%, medal and coins 2% and other sectors 2%. There exists a huge gap between demand and indigenous production, which is likely to continue.

Modernization of Technology in Gold Exploration/ Mining/ Mineral Processing.

Some of the challenges and opportunities that the gold exploration and mining industries has to give thoughts in the state-of art present day scenario and in order to address the future challenges of safe, sustainable and eco-friendly gold exploration and mining (Sangurmath, 2022).

✤ The existing status of regional / preliminary /detailed gold exploration is mainly restricted to search for ore deposits in and around ancient / modern mine workings. So far, traditional exploration has been done following surface outcrops and old workings. Since most of these direct targets have been investigated.

✤ We have to look for deposits in virgin area, hidden wholly below the ground by application of sophisticated methodology/equipment and technology such as :

✤ Conceptual exploration by geological modelling. The available geo-data to be reinterpreted, other information to be organized, basic criteria characteristics of mineralization must be recognized. A shift in the basic approach from conventional "Prospect" oriented approach to "Prospect in the regional Geological setting approach to be studied." Geo-modelling of the geo-data and by analysis, synthesis of case studies may yield more information to locate a new auriferous zone.

✤ A more vigorous exploration strategy is required, emphasis being laid on the identification of large size deposits of low-grade ore amenable to opencast method of mining.

✤ Use of Remote sensing techniques with satellite imageries and aerial photos. Ground and air-borne Geophysics. Use of on-site portable analysers, Geochemistry, Vapour geochemistry.

✤ In case of detailed exploratory mining, which account for major share of exploration inputs and optimize the quantum of exploration without sacrificing the detailed exploration reliability and accuracies of geometry of ore, reserves, and grades.

✤ The Exploration in underground should

a) Use small diamond drilling machine to explore the HW and FW contacts/ mineralisation to avoid the x-cut mine development works.

b) Cavity Monitoring System (CMS) should be utilised for the underground stope survey and stope inventory monitoring (TRF & GRF).

c) Ore Sorting Technology (OST) may be examined to segregate waste rock from the ore & thereby enhance the recovery of gold.

d) Sampling should be carried out by chip cutting machine.

e) Process Audit from mine to mill :

i. The run-off mine grade of the ore being considered as the backbone for the survival of any gold mining, the economic feasibility, and the consistency in production of mine's planning needs meticulous exercise on grade control. The grade control process at the mine sites by Geologist's involves two stages. i.e (1) Optimization of the sampling and (2) Interpretation of ore and waste limits and grade monitoring in underground mine & mill.

ii. It is very much necessary to take concrete steps to bring down the variation in the Mine and Mill grades :

iii. The variation noticed in the underground mine grade (ROM) and mill grade (Recovered) is to be audited from the stage of Exploration, Mining and Metallurgy. This allows the results to be reconciled against planned mine production and actual metallurgical plant data. Minimizing the difference between planned and actual production will improve gold mining business performance.

✤ Review of case histories used in country and other parts of the world with correlation of complexity of ore body with investment needs etc.

✤ Induction of checks and counter checks in sampling, sample preparation and analysis.

✤ Modernization of cartographic methods.

✤ Geostatistical methods for optimization of exploration programme and reserve estimation.

✤ Ore beneficiation and metallurgical studies to absorb modern technology to search for and appraisal of ore bodies of marginal grades mineral deposits.

✤ The entire Gold Exploration, Mining, Metallurgical, Engineering, and associated works should be modern, cost-effective, incorporating state-of-the-art equipment's, machineries, and processes.

✤ Determine in-situ relationship & recovery of gold with copper in polymetallic sulphide deposits. i.e, Ingaldhal, G R Halli, Ajjanahalli, Kalyadi, Thintini, Machnur & Kallur Copper Deposits etc.

✤ Gold occurs in a variety of geological settings and a clear understanding of the processes leading to concentration of gold in specific environments is necessary. Attention mustbe given to basic researches on Archean gold-fluid inclusion studies, isotope studies, geochronology, structural controls on mineralisation and studies on physico-chemical conditions of gold deposition.

✤ Gold mineralisation in different geological environment to be studied in detail for further exploration & mining.

✤ Petrological, Mineralogical, Geochemical & Fluid inclusion, stable isotopes (carbon, sulphur & oxygen), thermodynamic studies, geochronology, micro geological structures, mineralising fluids, age of mineralisation, aclear understanding of the mechanical processes responsible for the development of shear zones which are the loci for gold mineralisation, the host & mineralised zones should be dated, individual metamorphic minerals to be dated to decipher the metamorphic history of polygenetic deposits, collision of different crustal blocks, Wall rock alteration. etc, studies.

✤ The mineralisation in the contact of Schist belt and Granites to be studied for further exploration & mining.

✤ Komatiitic basalts, metapyroxenites in Bullapur Formations of Hutti – Maski Schist belt & in other areas to be studied for further exploration & mining.

- ✤ Recovery of multi-metal from mine waste and tailings.
- ✤ The recognition can be obtained from National Mineral Exploration Trust (NMET), Ministry of Mines, Govt of India as a nodal agency for Exploration.
- ✤ In order for the mines to produce ore on a sustainable basis to remain profitable, one tonne of ore mined has to be replaced by one tonne. This requires to explore one tonne of ore & develop one tonne of ore over many levels below the production levels.
- ✤ Deep Underground Mining Problems should be addressed scientifically :
  - a) Temperature
  - b) Underground Fire
  - c) Rock bursts
  - d) Ground Water Problems & Utilisation
  - e) Ground Water Problem in underground mine :
- ✤ Ore quality (grade) control in underground by ore zone demarcation, controlled drilling, blasting & mucking. With pre-split blast design etc & due diligence ore dilution (grade) to be controlled in underground.
- ✤ R & D in mining methods, mining equipment's, energy conservations, mine safety. etc.
- ✤ Digitalization is the process of empowering, improving, or transforming business process by leveraging digital technologies. It helps to keep exploration, mining operations safe, optimise production, scheduling and material flow and track exploration and maintain mining performance in real times.
- ✤ The implementation of new technologies in the mining industry often lags behind that in other industries due to the harsh environmental conditions and the lack of awareness and exposure to these technologies in remote locations. Drones, IoT devices, wireless communication, Artificial Intelligence (AI), monitoring and control devices have the ability to carry a set of sensors for measuring various parameters and collect this information over a large area quickly. Geotagging of each datapoint allows the assessment of many parameters with the required spatial reference and the analysis of this data can yield interesting and useful results. Compliance with relevant regulations can also be made more convenient using drone-based technologies using various sensors.
- ✤ Recovery of gold from scavenged woodchips generated from gold processing plant.
- ✤ Metallurgy Department should adopt the very competitive gold processing technology with the rest of the gold industries across the globe.
- ✤ Bio-leaching studies of Refractory Gold ore etc.
- ✤ Geo Tourism and Harvesting of the Underground Mine Water.

Discussions

- ✤ Public Private Partnership (PPP) model may be examined for exploring & mining the gold etc deposits.
- ✤ Underground Mining should address on a) Mineral Exploration b) Mechanization for Higher Production c) Mineral Conservation d) Digital transformation in Mining e) Health, Environment, and safety etc., which is need of the hour.
- ✤ Of late, the concept of privatization is riding high. Coal mining de-nationalization is one such example and now coal blocks are offered to private industries for captive consumption to meet the energy requirements of the nation. Similarly, the Hindustan Copper Ltd (HCL), and Hindustan Zinc Ltd (HZL) have been taken over by Vedanta.

- ✤ It is imperative for the Underground Mining sector to adopt best practices available globally for increasing productivity and efficiency.
- ✤ Learn how the latest techniques in addressing industry labour issues could come to benefit gold production, skill developments, CSR. etc.
- ✤ The lengthy process of prospecting, exploration, developing and establishing new gold mines in the country should receive serious consideration at all level of decision making.
- ✤ Ambition needs to be stirred in smart expert businesses to reach out boldly and tirelessly, towards success awaiting enterprising Geologists/Mining Engineers/Metallurgists and Investors. It is wrong to stand still and stagnate when large opportunities are present for making immense progress through new discoveries and massive gold ore productions.

Finally, Good hunting…….. Wherever You Are!!

ACKNOWLEDGEMENTS

The data/ information gathered by other agencies were necessary to present a comprehensive review attempted in this note. The author wishes to thank the authors of such reprints/papers /notes and reports.

Note :

- Views expressed in this paper are not necessary those of organization in which author has worked or is working.
- The information and expressions of opinions contained in this paper are not intended to be a comprehensive study, nor to provide actuarial advice or advice of any nature and should be not be treated as substitute for a specific judgement.

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Theme of the Next Issue of
MGMI News Journal

Vol. for 50, No . 1

Exploring India's Critical Mineral Wealth : Prospects and Challenges

PRAGMATIC APPROACH TO STRATEGIC MINE PLANNING TO DEAL WITH MARKET PRICE UNCERTAINTIES : A CASE STUDY ON BASE METAL DEPOSIT

Suryanshu Choudhury

Abstract

Open pit optimization and scheduling tasks are important part of mining venture that has attracted considerable attention to the mining industry since couple of decades back. Determination of optimum pit has got significant effect on calculation of life of mine which involves huge capital investment. Present paper addresses on the application of Whittle optimization software and Minesched scheduling software for optimizing and then life of mine scheduling for a copper-cobalt deposit located at central African copper belt. The methodology used was to generate a series of pit optimizations from the resource model and then subsequent strategic mining scheduling based on the optimized pit, including capital expenditures consideration and cash flow analysis. The deposit is optimized to 9.1 Mt with an average copper grade of 2.03% and cobalt grade of 0.47%. Based on the calculated optimum pit the life of mine is forecasted for 6.5 years.

Key words : *Pit optimisation, Scheduling, Modelling, Whittle, Minesched.*

Introduction

Modern open pit mine involves huge capital investments due to the scale of mechanization. It is obvious that there is critical need for a clear delineation of ultimate pit configuration as well as proper life of mine schedule on the basis of maximum financial advantage before to start a mechanized open pit mine. Pit optimization plays a major role in all stages of the life of an open pit: at the feasibility study stage when there is a need to produce a pit design for whole life of mine; at the operating phase when pits need to be developed to respond to changes in metal prices, costs, ore reserves, and wall slopes; and towards the end of a mine's life where the final pit design may allow the economic termination of a project. At all stages there is a need for constant monitoring of the optimum pit, to facilitate the best long-term, medium-term and short-term mine planning and subsequent exploitation of the reserve. The optimum pit and mine planning are dynamic concepts requiring constant review. Thus the pit optimization technique should be regarded as a powerful and necessary management tool. Further, the pit optimization method must be highly efficient to allow for an effective sensitivity analysis. In practice one needs to construct a whole spectrum of pits, each corresponding to a specific set of parameters.

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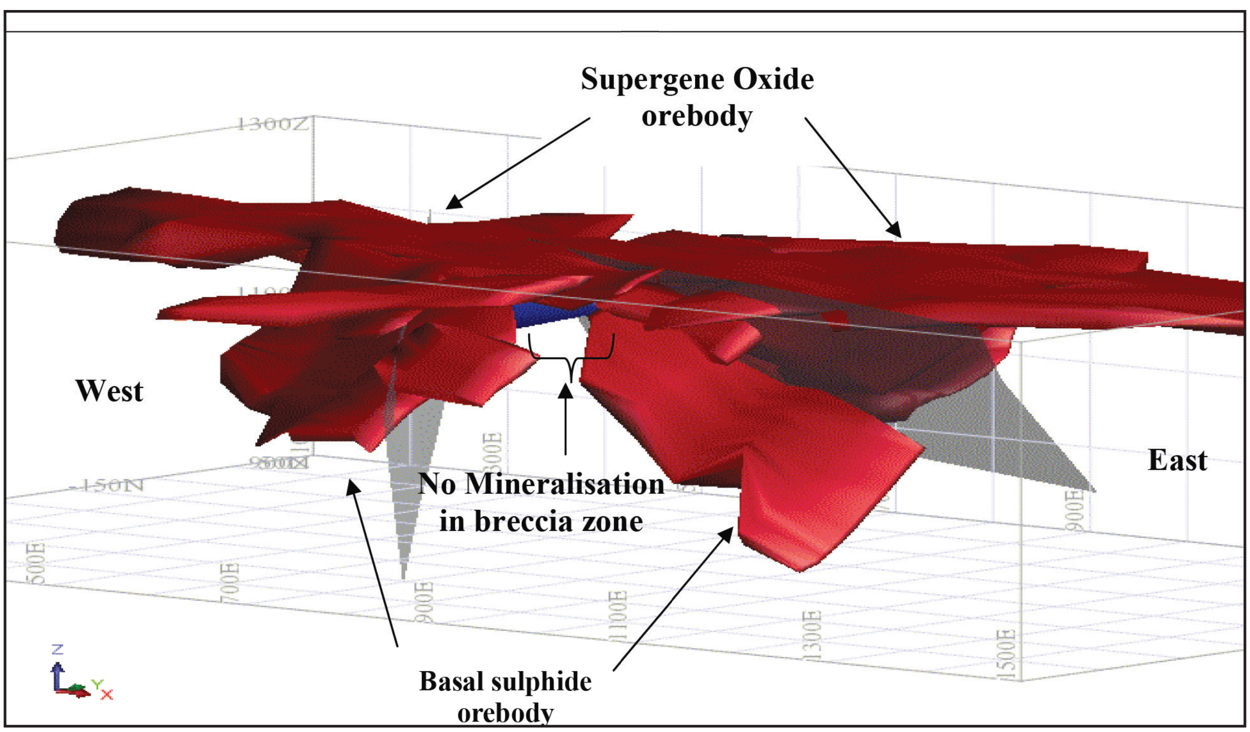
The operation and management of a large open pit mine is an enormous and complex task, particularly for mines having a life of many years. Optimization techniques can be successfully applied to resolve a number of important problems that arise in the planning and management of a mine. These applications include : ore-body modelling and ore reserve estimation; the design of optimum pits; the determination of optimal production schedules; the determination of optimal operating layouts; the determination of optimal blends; the determination of equipment maintenance and replacement policies; and many more (Caccetta and Giannini [7-9]).

Brief on Geology and Mineralisation of case study area

the deposit under study in this paper is located at Central African Copper belt. The Central African Copper belt is spread over a great arc of folded Katangan sediments known as Lufilian Arc, extending for some 750 km in total from Mwinilunga in the west to Ndola in the east. Geologically the deposit is a stratiform copper-cobalt deposit similar to many other deposits in this belt. The copper-cobalt mineralisation was probably developed in Lower Roan Group dolomites, shales and fine sandstones during their compaction and diagenesis. Two principal stratiform mineralised horizons are developed and identified as the Upper and Lower Orebodies. The extension of the deposit has been traced at surface for a distance of approximately 1,400m and to a maximum vertical depth of 250m. Over much of this strike length it dips at 30-45^{o}, but near the surface it steepens to near vertical or is overturned (as at the western end). The footwall of the deposit is marked by a thrust zone or breccia, the thrust zone sometimes splits and cuts across the orebody, there by truncating it. It can be mineralised. This mineral is deleterious in the flotation of sulphide minerals. Down-dip the orebody is cut off by an approximately E-W trending and relatively steep fault. This limits the extent of the orebody with depth.



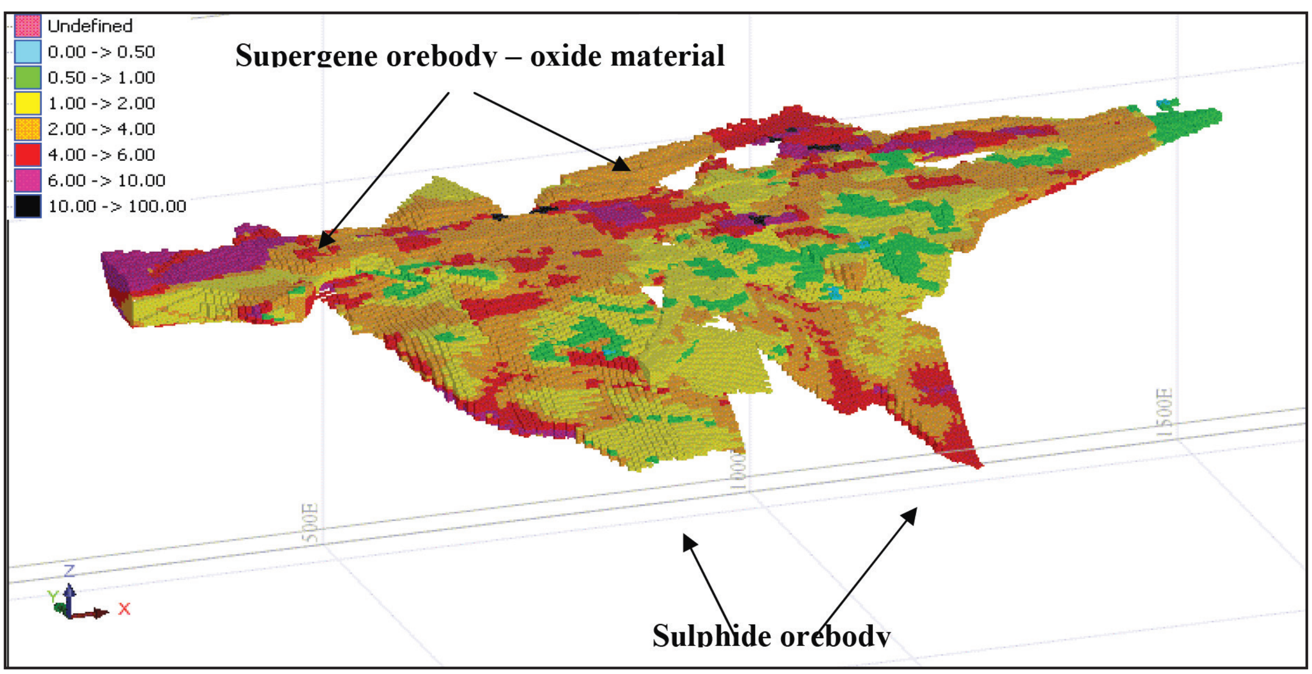
(Figure-1 : Ore body Model showing Oxide and Sulphide Ore bodies)

The whole orebody is divided into three types as Oxide, Mixed and Sulphide ore body (Figure-1). The oxide orebody is basically near surface supergene enriched horizon. The primary copper minerals (chalcopyrite and possibly bornite and digenite) and primary cobalt minerals (linnaeite and carrollite) principally occur as thin, discontinuous bands in the Upper and Lower orebodies. As a consequence of hydrothermal activity and supergene enrichment, the orebody has been partially oxidised to a considerable depth from surface. During this oxidation process, chalcocite, cuprite, malachite, native copper and chrysocolla replace the primary copper sulphide minerals, while heterogenite replaces the primary cobalt sulphide minerals. The depth of oxidation from the surface is dependent to some extent on the permeability of the host rocks and on the presence of brecciation associated with the basal thrust. Mixed ore body lies at the contact area of oxide and sulphide ore bodies.

Ore Body Model

In order to define the limit of ore body a cut-off grade of 0.5% TCu (Total copper) and 0.2 % TCo (Total cobalt) were used as prime criteria. The interpretation of ore body is based on the 50m spaced section lines. However, cognisance was taken of the individual assays and the orebody was interpreted based on the drill hole positions. The block model was constructed with blocks of 12.5m x 12.5m x 5m (Figure-2). The block size of 12.5m in the X and Y direction has been based on approximately quarter the average drill spacing. The block height of 5m is based on a sub-divisible mining height. It is believed that at least 50% of blocks will have a drillhole located within them.

When considering estimation methods, the oxide and mixed material were taken to be a single unit, with a hard boundary between it and the underlying sulphide material. The oxide, mixed and sulphide material have been reported separately.



(Figure - 2 : Block model of the deposit Colored as per Copper grades)

Total resource estimated as 12.2 Mt at average 3% Copper and 0.5% cobalt for oxide and mixed materials only. Sulphide resource estimated separately as 9.2 Mt at 2.9 % Copper and 0.33% cobalt.

Pit Optimisation

With the progress of mining in both directions horizontally and vertically, unit cost of mining increases because of increased haul distance, increase in waste handling and mine dewatering etc. Finally a stage is reached ultimately where the marginal profit is wiped put. This is also the stage where the total profit for the whole mine is maximum. The configuration of pit at this stage is optimum one. In other words, the final pit limits define what is economically mineable from a given deposit. Basically it identifies which blocks should be mined and which ones should be left in the ground. In order to identify the blocks to be mined, an economic block model is created first from the geologic grade model. This is done by assuming production and process costs and commodity prices at current economic conditions (i.e. current costs and prices). Then using the economic block values, each positive block is further checked whether its value can pay for the removal of overlying waste blocks. The analysis is based on the breakeven calculation that checks if undiscounted profits obtained from a given ore block can pay for the undiscounted cost of mining the waste blocks.

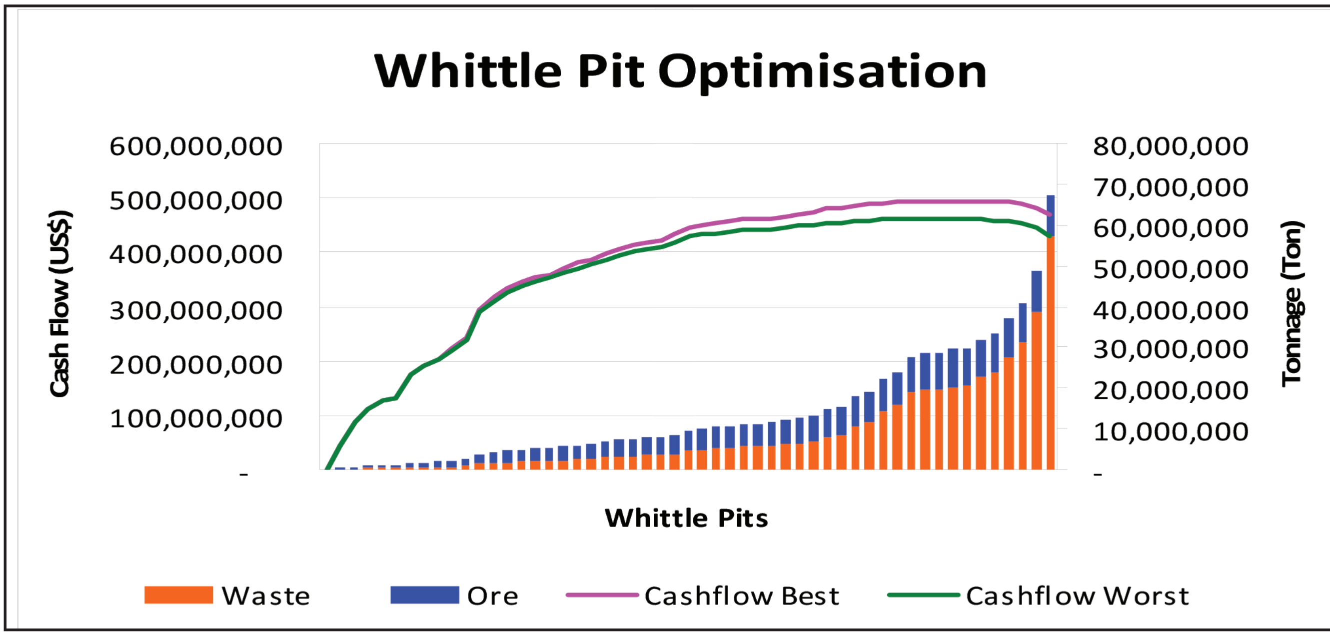
Whittle Four-X™ multi-element optimisation software was used to determine the pit limits for this deposit. Pit optimisations were carried out on the geological model. Operating cost, price and slope estimates and reprocess recoveries were used in these optimisation runs. For a given block model, together with cost, recovery and slope data, Whittle Four-X™ software calculates a series of incremental pit shells in which each shell is an optimum for a slightly higher commodity price. The sequence of the pit shell increments is sorted from the economically best to the economically worst. Whittle generates estimated Net Present Values (NPV) using time discounting of cash flow for two mining sequences identified as the "best case" and "worst case" scenarios. In the "best case", the optimum pit shells are mined bench by bench in increments from the inner to the outer shell, resulting in a higher NPV due to lower stripping ratios and/or higher grades in the early years of the mine's life. The "worst case" scenario is based on mining the whole pit outline bench by bench as a single pit, hence resulting in a lower NPV because of higher stripping requirements in the early years of the operation. In real life, a mine operation can approach a "best case" with good, practical, staged design and the adoption of an appropriate cut-off and stockpiling strategy. It is important to note that the cash flows presented in the analysis of pit optimisation results exclude capital costs and are based on operating costs only.

1. Base Case Optimisation Results

Optimum pit shells for the project, obtained in the base case optimisation, provided the basis for the generation of the detailed pit designs. The base case pit optimization results are calculated which include ore and waste tonnages and NPV's (Cash values) for the incremental pit shells with all of the data. The estimated net cash flows have been calculated in Whittle using the variable unit value estimates. For the purpose of this study pit shell selection was based upon the pit that generated the maximum net present value. In present case pit shell number 59 produced a maximum incremental best case pit value of US$ 494.4 M, and worst case pit cash value of US$ 461.0 M.

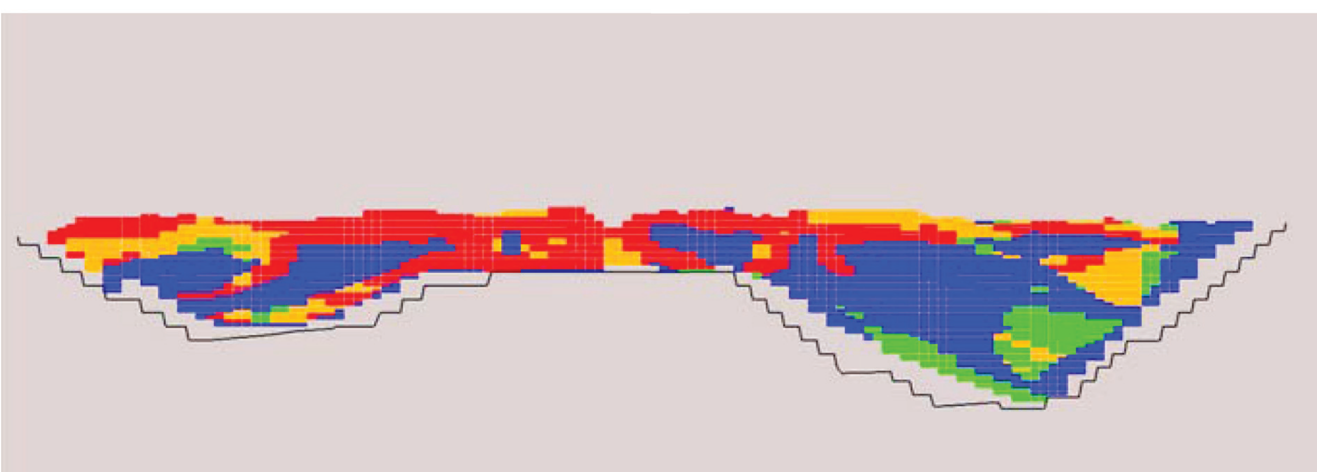
The estimated results associated with this optimised shell are :

- 9.1 Mt of ore at an average AS Cu of 2.03% and Co of 0.47%
- This produces an optimal pit life of 6.5 years
- The material is sourced at a strip ratio of 2.22 : 1.



(Figure-3 : Optimisation Results – Pit Number vs Estimated Net Cash flow)

The estimated net cash flow plotted against pit shell inventory for each successive pit shell as shown in Figure - 3. Project value increased initially, as the pit size increased, reaching a maximum value for pit shell 59 (494.4 Mt) after which the cost of the next successive cut-back exceeded the revenue that could be expected from the additional ore produced and the project value began to decline. It is significant to note that pit optimisation indicates the pit shell tonnages can be decreased by as much as 35% without having a significant impact on the estimated net cash flow (1% reduction). Conversely, the mining tonnages can also be increased for a marginal reduction in estimated net cash flow. A 26% increase in tonnages results in a 1% drop in cash value of the pit. The optimal pit extracted for optimal whittle pit 59 produces a pit 800 m (East-West) by 450 m (North South) by 140 m deep.



(Figure-4 : East-West Cross Section through the Design showing Block Model Constrained using the Optimised Pit Shell)

Life of Mine Scheduling

Open pit production scheduling is the development of a sequence of mining blocks leading from the initial conditions of the deposit (i.e. original topography) to the ultimate pit limits. The aim of mine scheduling is to generate a plan or schedule of mining selected parts of the ore body that will ensure delivery of the budgeted tonnes and grade of the raw material to the mill in the period under consideration. Specifications vary depending on whether the plan involves long, medium or short term scheduling. The first stage of scheduling within the software is to model scheduling precedences. These include activity precedences (for example drilling, blasting, mining), location precedences (where the user may have specified that a location cannot start until another location finishes), and mining block precedences. Mining block precedences are always calculated between blocks within the same location. Optionally they may be calculated between blocks in different locations. Correct modelling of precedences ensures that user defined rules and practical mining constraints are honoured. The second stage within the scheduling engine is to model the resources. All scheduling operations in the software are resource driven. A resource distribution network is modelled, which is later used by the target scheduling engine for efficient resource allocation. The third and final stage prior to starting scheduling is to model the material flow network. Material mined from static mining locations may be sent to dynamic mining locations, and from these dynamic mining locations onto further dynamic mining locations. Material can be split at nodes in the network based on material classification and based on product targets.

Based on the optimized pit the Life of Mine Schedule for the deposit calculated in order to assess the capability of the deposit to deliver quality targeted materials to the process plant at a sustainable rate while still maintaining practical mining methods. The scheduling exercise performed by Minesched scheduling software. Minesched is an automated scheduler that uses a mathematical model to represent the mine and its production constraints. Minesched uses a combination of algorithms that are used to compute a production forecast, which satisfies the production constraints and optimises the schedule.

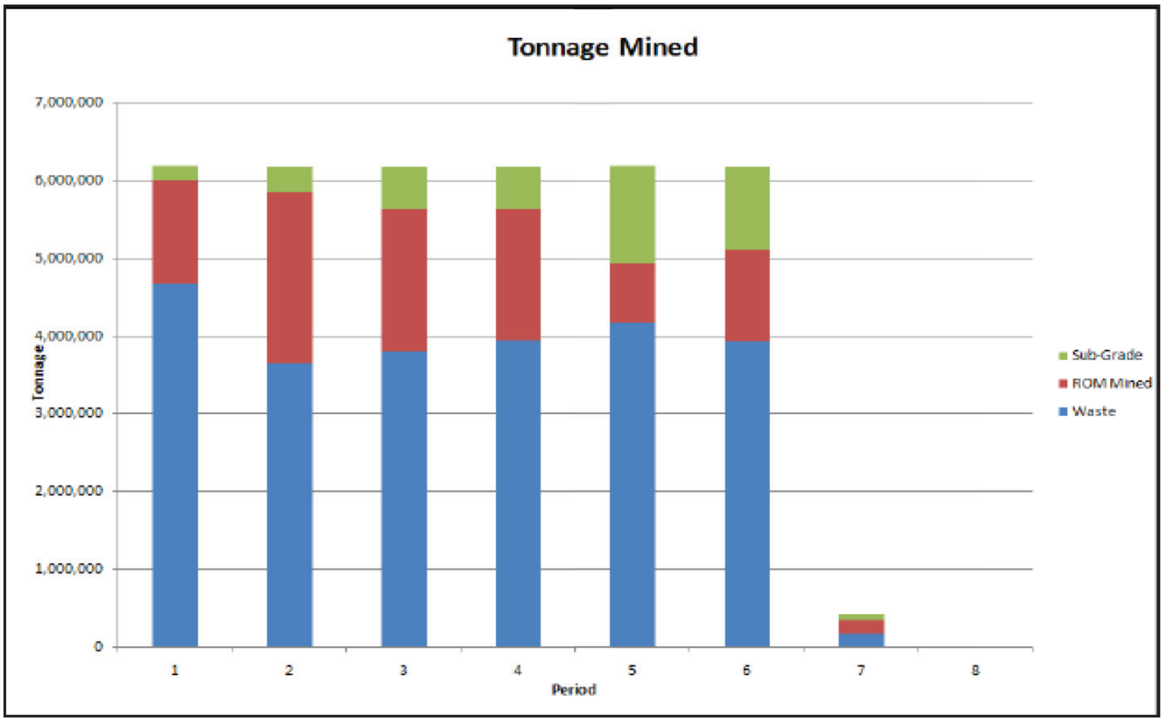
The following steps were taken in preparation of the scheduling process :

- ➢ Definition of ore materials and waste within the pit limits;
- ➢ Definition of operational Mining Areas
- ➢ Definition of production resource capacities
- ➢ Definition of Plant capacity and feed rates
- ➢ Identification of quality targets to maintain homogenous feed to the process plant

The scheduling process involved a number of iterations to assess the impact of alternative mining sequences to obtain the required result from the plant. This involved the definition of a new material type; Sub-grade which contains all of the ore materials with an AS Cu (Acid Soluble Copper) value of less than 0.5%. The scheduling exercise performed based on following targeted parameters.

- ➢ Target mill feed grade : TCu 2.1% (Variation between 2.05% minimum and 2.2% as the maximum)
- ➢ AS Cu 2.19% : 0.54% TCo (No target for AS Co)
- ➢ Annual production target 6.1 Mt (Including ore and waste)

Mined Materials sent to a ROM (Run of Mine) stockpile for all materials with AS Cu of greater than 1%. The subgrade materials stockpiled separately. The graph in Figure-5 represents the movement of material as per period of the schedule.



(Figure - 5 Movement of material as per period of schedule)

Conclusions

A fundamental problem in mine planning is that of determining the ultimate pit limit of a mine. The optimum ultimate pit of a mine is defined to be that contour which is the result of extracting the volume of material which provides the total maximum profit whilst satisfying the operational requirement of safe wall slopes. Usually, this contour is smoothed to produce the final pit outline. Determination of ultimate pit limit is necessary for determining the life of the mine and capital investment involved which ultimately influences the size and number of equipments, location of plant and waste dumps etc. The deposit under study in this paper consists of three types of ore in the deposit as oxide, Mixed and sulphide. Preliminary exercise has been carried mainly to optimize the oxide and mixed type ore. The sulphide ore body was not considered for optimisation because it was part of inferred category resource for which detail exploration planned for converting the inferred sulphide resource to measured category. The deposit is optimized at 9.1 Mt of ore with an average AS Cu of 2.03% and Co of 0.47%. The life of mine is forecasted for 6.5 years. The average stripping ratio is 2.22 bcm: 1 tonne. The net present value at the optimized pit (pit shell 59) is US$ 494.4 million.

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DEVELOPMENT OF VIRGIN MINERAL DEPOSITS – SOME SUGGESTIONS

D N Bhargava

This paper presents some suggestions how the "Development of Virgin Mineral Deposits" could be achieved in an environment of peace and harmony, and regulation of the mining activity could be done in an effective and efficient manner so as to simplify the regulating mechanism yet maintain the scope of regulation.

It takes into account the current practice of auction of Mineral bearing areas, allotting each to the highest bidder. Also, there are indefinite delays in grant of various approvals which retard the commencement of production of minerals. These factors are bound to inflate the cost of production of the respective minerals; this inflation may eventually be passed on to the consumers. Keeping the above factors in view, certain views and suggestions are being offered below; if adopted these may simplify the procedures, promote "Ease of doing mining" and guard against inflation

The current situation and suggestions offered for adoption.

1. A mineral deposit is first identified in the course of geological mapping of a region by the Geological Survey of India (GSI). Just then mutual consultation between the Ministry of Mines and the Ministry of Environment & Forests is necessary about the future clearance of such an area for the grant of mining lease even before the detailed exploration of the mineral deposit is undertaken. This will ensure the availability of the sites for detailed exploration and subsequent mining operations subject to observance of certain conditions for the conservation of the Mineral resources and the protection of Environment. It will do away with the need for further approvals by the Ministry of Environment or the Ministry of Mines and save valuable time during the start-up of mining operations.
2. The detailed exploration of the mineral deposit is being undertaken by a number of Agencies. It includes the GSI and Directorates of Geology of different States. Certain Agencies of the Central Government such as the Mineral Exploration and Consultancy Limited (MECL), Coal Mine Planning and Design Institute (CMPDI) also undertake detailed exploration. The mining lease holders are required to pay a mineral exploration cess which in a way makes up for the expenses made by the Governments or their agencies on exploration.
3. In case a viable mineral deposit is identified for the grant of mining lease, the concerned Government may rehabilitate in advance the persons, who are likely to be displaced as a result of the grant of mining lease, at another suitable site; the Government may recover the cost of such rehabilitation from the applicant who is subsequently granted the mining lease of the said area. The M.L. Holder would gladly reimburse the cost of rehabilitation, because it will save him valuable time before the commencement of the mining operations.

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4. Once the decision of clearing an area for future mining is taken as discussed at (1) above, the Ministry of Environment may specify the environmental conditions which should be met, keeping in mind that during the conduct of mining operations, some amount of degradation of environment would be inevitable. It may also specify the extent to which the environment may be restored in the course of the mining operations and before the closure of the mine.

5. The concerned officers of Ministry of Environment may monitor the mining operations thereafter, but the need for any grant of approval for the mining operation should not arise. Since the Officers of the Indian Bureau of Mines are also the authorized officers under the Environment Act, the Ministry of Environment may point out, if necessary, any lacuna to IBM. Then it will be IBM's responsibility to ensure that the lacuna is removed by the Mine Owner. Even otherwise IBM may on its own do so.

6. Whenever mining lease is granted of an area which had already been explored by a Government Agency in the past before the provision for payment of exploration cess was made, it may be made mandatory for the applicant for mining lease to reimburse the cost of exploration, and he may be provided the detailed exploration report. He may be permitted not to pay the exploration cess until such time that it is adjusted against the lump-sum payment already made. Thereafter he may be required to pay the exploration cess for exploration in the same way as is obligatory for the others.

7. It is experienced that the displaced communities are often antagonistic to mining. To gain their goodwill and change their mind-set it may be advisable to let the Gram Panchayat of the mineral bearing area also take up mining. They may be encouraged to form a cooperative and hold the administration of the mine; they may engage the Mining Corporation of the concerned State as the Consultant; the Corporation may be assigned the technical work involving the management of the mining operations.

8. The grant of Mining lease should be delinked with the practice of granting it to the highest bidder. Instead the applications for the grant of lease may be considered on the basis of how the applicant would serve the public interest by the way of rehabilitation of the displaced people or indicating the concrete steps he would take to serve any other public interest. The offers may be transparently scrutinized for taking decision regarding the grant of mining lease.

DR. PRABHAKAR SANGURMATH, LIFE MEMBER, MGMI RECEIVES PRESTIGIOUS S. NARAYANASWAMI AWARD-2023 FROM GEOLOGICAL SOCIETY OF INDIA

Dr Prabhakar Sangurmath, a Life Member (LM-10033) of MGMI was awarded the prestigious S. Narayanaswami Award - 2023 by Geological Society of India for his outstanding contribution in the field of Economic Geology. Dr Sangurmath hails from the Adur village, Tal: Hangal, Dist. Haveri, Karnataka state. He has an excellent academic record with M. Sc (Applied Geology) from Karnataka University & Ph.D (Economic Geology) from Gulbarga University, Karnataka.

Dr Prabhakar Sangurmath had an illustrious career as a geologist, first with the Mineral Exploration Corporation Ltd (MECL) and later with Hutti Gold Mines Co. Ltd (HGML). During his 38-year tenure with these organizations, he worked diligently and excelled in various roles and superannuated as the Executive Director of HGML. Through his unwavering dedication and sincere efforts, Dr. Sangurmath established himself as an eminent exploration and mining geologist, an accomplished manager, and a proficient technocrat. His expertise lies in the identification of economically viable gold and base metal mineral properties for exploration, mining and processing.

Dr Sangurmath is known for his exceptional combination of professional excellence, effective management, extensive research contributions, and strong academic acumen. His detailed exploration programs and research studies at the Maski-Buddini Gold Deposit in the Raichur district of Karnataka provided invaluable insights into mineralization geometry, modes of occurrence, ore characteristics, controls, and guidelines for gold mineralization, as well as exploration and mining methodologies. He successfully applied these principles to the search for ore at the Uti, Wondalli, Hira-Buddinni, Hutti etc. Gold Deposits, leading to the establishment of the Uti open-pit gold mine. He played a pivotal role in establishing a top-tier core library, a geology museum, and an exploration/mining data bank center at Hutti. He is also the author of numerous reports and research papers published in both national and international journals. He has also served and serving as Member, Convener and Chairman of several committees on exploration, mining, environment management, statutory regulations and related research and development. He has guided and adjucated Ph.D\M.Phil\M.Sc thesis. He developed the deep underground gold mines brick by brick with his team. Dr Sangurmath has exemplified his role as a leader and taken his teams from strength to strength as a high performing Executive Director. His scientific knowledge and administrative capabilities have enhanced the economics and the image of HGML. In recognition of his outstanding work, Dr Sangurmath has received numerous awards, honors, and accolades, including the prestigious (i) "*National Geo-Science Award*" from the Ministry of Mines, Government of India, (ii) Master Tanay Chadha Memorial Geologist Award from MEAI, (iii) Dr P N Bose Memorial Award from IE and MJ, and (iv) Dr J Coggin Brown Memorial Gold Medal from MGMI, as well as fellowships of important professional academic bodies like GSI, ISAG, IGC, MGMI, ISCA, KRVP, MEAI, SGAT etc.

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