August 2019

DISCUSSION PAPER

EXPLORATION AND MINING IN INDIA: TIME FOR A DEEPER LOOK

S Vijay Kumar

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Author

S Vijay Kumar, Distinguished Fellow, TERI

email: SVijay.kumar@teri.res.in

External reviewer

Mr A K Bhandari, Deputy Director General, Geological Survey of India (retd.)

About the Author

S Vijay Kumar was earlier in the Ministry of Mines as Additional Secretary (2008–10) and Secretary (2010–11). In TERI he works on issues concerning resources and rural development, and heads the cross-cutting initiative on policy coordination and the SDGs. He is also a member of the International Resource Panel of UN Environment.

Suggested format for citation: Vijay Kumar S (2019). Exploration and mining in India: time for a deeper look. TERI Discussion Paper (New Delhi: The Energy and Resources Institute)

Editorial and design

Abhas Mukherjee, Sudeep Pawar

PUBLISHED BY

The Energy and Resources Institute (TERI)

FOR MORE INFORMATION

Integrated Policy Analysis Programme, TERI, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110 003, India
Tel.: +91 11 2468 2100 or 2468 2111 | Fax: +91 11 2468 2144 or 2468 2145
Email: pmc@teri.res.in | Web: www.teriin.org

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EXPLORATION AND MINING IN INDIA: TIME FOR A DEEPER LOOK

Summary

India has a high geological potential for minerals. Most of the minerals on or just below the surface have been located and there is a need to look deeper for concealed mineral deposits. This means conducting mineral exploration on a continuous basis through the latest technologies. However, according to the internationally reputed Fraser Annual Survey 2016, India has been ranked 88 in the Policy Perception Index, 94 in the Best Practices Mineral Potential Index, and 97 amongst 104 jurisdictions for Investment Attractiveness Index. India is thus in the bottom ten countries.

The Mines and Minerals (Development and Regulation) Act 1957 (MMDR Act) was enacted at a time when the public sector occupied the commanding heights of the economy. A reform-oriented National Mineral Policy was announced in 2008, which stated that exploration and mining will be recognized as independent activities with full transferability of concessions; and that the private sector should be the main source of investment in reconnaissance and exploration.

In 2015, the Mines and Minerals (Development and Regulation) Act 1957 (MMDR Act) was amended with the intention of removing discretion and introducing more transparency in the allocation process. Auctions were made the only mode of grant of concessions. A National Mineral Exploration Policy (NMEP) was brought out by the Government in 2016 followed by the National Mineral Policy 2019, which states that "the private sector should be encouraged" to take up exploration; and that "exploration should be incentivized to attract private investments as well as state-of-the-art technology, within the ambit of the auction regime, through Right of First Refusal at the time of auction."

This paper suggests that by making auctions the sole mode of granting concessions, private sector has been disincentivized from making the requisite investments in fresh exploration, which is necessary to enable a steady stream of mineral deposits for exploitation. The Paper points out that the link between exploration and mining seems to be well understood by the Courts. The Supreme Court in its Opinion dated September 27, 2012 on a Reference by the President of India has stated, (Special Reference No.1 of 2012 under Article 143(1) of the Constitution of India), that auction is not the only way of discharging a public trust while alienating natural resources.

The paper also brings some of the issues arising from the new approach embodied in the amendment of the MMDR Act and revision of the Mineral Policy:

1. Auctions can still be subjective and non-transparent because the current methodology of valuing mineral resources is not meant for the purpose. A more robust system of reporting of mineral resources, such as JORC, needs to be used, rather than the current UNFC system if the uncertainty, incompleteness, and arbitrariness is to be reduced.
2. The MMDR Act as amended introduces the concept of "captive" and "non-captive" mining. By segmenting the market and creating a perception of resource scarcity, auctions for "captive" mines will lead to unnaturally aggressive auction bids by the metal makers (for fear of stranded assets) with every possibility of a "winners curse" given the volatility to which the market in this sector is subject. The amendment to the Act also creates a non-level playing field since CPSUs are allocated mines without auction.
3. The system does not incentivize market efficiency. The auction system should be used for fully prospected deposits only, and without any distinction between captive and non-captive mines, so that a free market for ores develops and the resources are used most efficiently taking into account forces of supply and demand. In the natural course, it will be minerals like iron ore, bauxite and limestone, which occur over large areas and are easy to prospect that will be auctioned. Such mines as are auctioned should be allowed to be worked through extension after every 20 or 30 years till exhaustion of the economically mineable portion of the deposit. This will ensure stability of tenure and

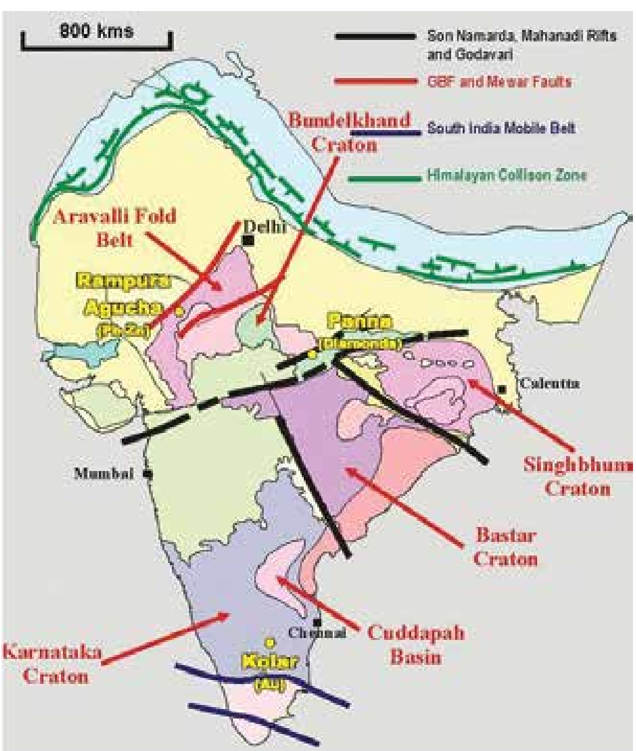
enable the concessionaire to do long-term investment and mine planning and make best use of the grades. At the same time, mineral concessions should be freely transferable to benefit from improvements in technology of extraction and processing.

4. As the country develops and industry and manufacturing grows, impelled by the "Make in India" policy, assured availability of mineral resources will play an important role in giving a competitive edge to the Indian industry in general and manufacturing in particular. Emphasis now needs to be given to the co-production of by-product metals from base metal ores through process R&D so that the country's needs of the so-called Technology Metals and Energy-Critical Metals are effectively met and provide raw material security on the one hand and a competitive edge on the other for the country's manufacturing sector. Exploration should improve India's mineral security and competitive edge, and not be made subservient to revenue generation through auctions.
5. Auctions have the potential to reduce the financial viability of the metal making industry and reduces competitiveness in the international market. Royalties, imposts, and costs need to be internationally benchmarked if "Make in India " is to be realized.
6. Given the complex and widespread nature of regulatory deficit generally in the mining sector, the time has come to create independent Mining Regulatory Authorities and Tribunals for technically sound and credible management of the sector.

SECTION 1: THE FRAMEWORK

Geological Background

India's geology goes back to the earliest times called the Archean period, over 2,500 million years ago. The Archaean formations in the Indian Shield[1] occupy most of the southern and eastern India and parts of Assam, Jharkhand, Madhya Pradesh, and Rajasthan. This was followed by the Proterozoic period which ranged from 2,500 to 570 million years ago. The Aravalli Range is a remnant of an early Proterozoic orogen. The Vindhyan ranges also belong to this period. This was followed by the Palaeozoic formations of India from 570 to 245 million years ago, when the major coal deposits were laid down.



The Indian Craton was once part of the supercontinent of Pangaea which was formed about 335 million years ago out of earlier existing landmasses (cratons). The forming of supercontinents and their breaking up appears to have been cyclical throughout Earth's history. Rifting caused Pangaea to break apart into two supercontinents, namely Gondwana (to the south) and Laurasia (to the north). The Indian Craton remained attached to Gondwana, until the supercontinent began to rift apart about 125 million years ago. The breakup of Gondwana separated the Madagascar–Antarctica–India landmass from the Africa–South America landmass. Australia remained connected to India and Antarctica until approximately 100 million years ago when India broke away and began moving north. The Indian Plate continued to drift northward and collided with the Eurasian Plate about 50 million years ago. Australia and Antarctica completely separated roughly 45 million years ago.

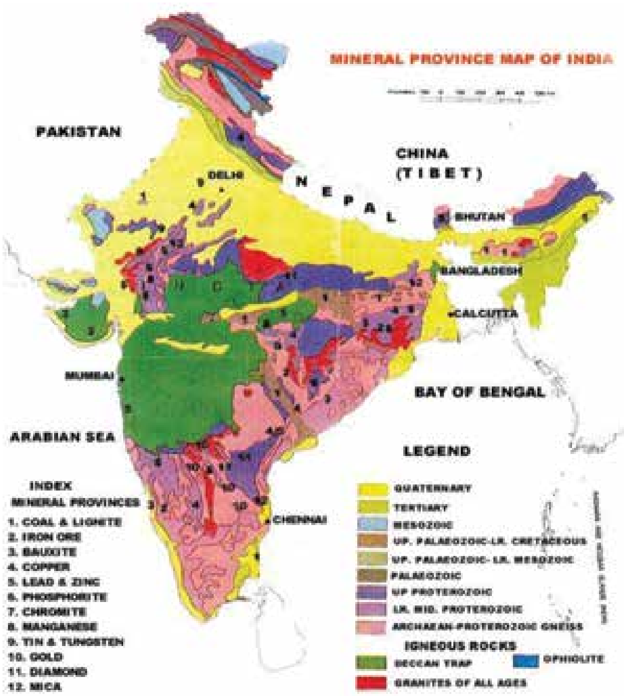
Parts of Western Australia and Southern Africa have a common geological history with parts of India for a considerable period and these areas can be expected to have some similarity in their mineral endowments. Given the proven mineral potential of Western Australia and Southern Africa, and considerable correlation between their mineral occurrences with India's known mineral formations, it is generally accepted that parts of India have the potential of hosting diverse mineral deposits, mostly yet to be discovered.

India in a Global Perspective

As is evident, India has a high geological potential for many minerals. Most of the minerals on or just below the surface have been located over the last 50 years and more and there is a need to look deeper for concealed mineral deposits. This means conducting mineral exploration on a continuous basis through the latest technologies. Historical evidence in advanced mining jurisdictions shows that in the case of common minerals of widespread use, such as iron ore and limestone, exploration more than replaces the stock of resources consumed through mining. A case in point is Australia whose iron ore resources have increased a hundred-fold in 40 years through a process of increased exploration and beneficiation, as cited in the Hoda Committee Report 2006.

The Ministry of Mines strategy paper 'Unlocking the Potential of the Indian Minerals Sector', published in 2011, highlights India's relatively low position in the global mining sector. The paper trenchantly states:

[1] Appendix 1 contains a Glossary of the main technical terms used in this Paper.



"As the relevance of the mining sector grows globally, the Indian mining sector is lagging behind, with just 1.2 per cent contribution to GDP over the last decade (as opposed to 5 to 6 per cent in major mining economies) and very low exploration spend per square kilometre (USD 9 [Rs 400] compared to USD 124 [Rs 5,580] for Australia and USD 118 [Rs 5,310] for Canada)…"

"India has initiated several progressive policy measures, putting itself in a good starting position to undertake the transformation of the mining sector. Unlocking the potential of the mining sector in India could add around USD210 billion to USD 250 billion (Rs 945 to 1,125 thousand crore) or 6 to 7 per cent to the GDP and create 13 to 15 million jobs through direct and indirect contribution by 2025.

To achieve this, action is required on six key priorities, including enhancing resource and reserve base through exploration and international acquisition; reducing permit delays; putting in place core enablers (infrastructure, human capital, technology); ensuring sustainable mining and sustainable development around mining; creating an information, education, and communication strategy; and undertaking measures to ensure implementation."

With vast resources lying unexplored, survey and exploration is the first step towards developing domestically available minerals for internal utilization in infrastructure, capital goods, and basic industries. Globally, economies with a large mining base or potential resources have projected significant spends (public and private) for exploration; however, Indian exploration budgets are still limited. It also needs to be noted that while the global investments in exploration have been rising in many countries, particularly after a reform process, a similar trend is not visible in the Indian subcontinent. A study on the Corporate Exploration Strategies (CES) of global companies by S&P Global Market Intelligence for the year 2016 highlights that the 20 companies with the largest non-ferrous exploration budgets in 2016 accounted for 31% of the global exploration of around $7 billion. The report also highlights that the top 10 companies accounted for $1 out of every $5 that was being spent on exploration globally. Copper, gold, and diamonds accounted for 88% of the total exploration budgets of the top 10 companies.

International exploration budgets are allocated based on the attractiveness of destinations. According to the Fraser Institute Annual Survey of Mining Companies 2016, Asia has the least attractive policy environment in the world. The Fraser Annual Survey undertakes a survey of countries globally to analyse their investment attractiveness and policy environment. The survey looks at various policy areas, such as mineral administration, enforcement of regulations, environmental regulations, legal and taxation regime, land, infrastructure, socioeconomic issues, political and security concerns, trade issues, etc., for analysis. India has been ranked 88 in the Policy Perception Index, 94 in the Best Practices Mineral Potential Index, and 97 amongst 104 jurisdictions for Investment Attractiveness Index which is a composite index that combines both the Policy Perception Index and results from the Best Practices Mineral Potential Index.[2]

[2] The top jurisdiction in the world for investment based on the Investment Attractiveness Index for 2016 is Saskatchewan (Canada) and Manitoba (Canada) moved up to the second place this year after ranking 19th in the previous year. Western Australia was third and the others were Nevada (USA), Finland, Quebec (Canada), Arizona (USA), Sweden, the Republic of Ireland, and Queensland (Australia). The Argentinian province of Jujuy ranks as the least-attractive jurisdiction in the world for investment. Also in the bottom 10 are 4 other Argentinean provinces as well as Venezuela, Afghanistan, India, Zimbabwe, and Mozambique.

The tables below provide an overview of the current comparative exploration allocations across the globe according to S&P Global Market Intelligence Data. As a pattern the first table reflects both the country's prospectivity for minerals as well as the attractiveness of the country's mineral laws for inviting investments. While Canada and Australia have been leaders in exploration for a long time, the emergence of Latin American countries as hubs of exploration is directly related to the reforms they have undertaken post 2000 to promote exploration through ease of grant of concessions and stability and predictability of their mineral laws which are translating into higher returns on investment.

In India, most of current expenditure on exploration is on coal, iron ore, and surficial minerals. By contrast, the largest proportion of global exploration spends are in gold, base metals (such as copper, lead, and zinc), and diamonds, as given in the second table. The high spends are also because of the inherent difficulty in locating these minerals, since they often occur beneath the Earth's surface. Appendix 2 gives some technical details of the process of formation of such mineral deposits.

Given its geological make-up, India is highly prospective for all three (gold, base metals, and diamonds), and as such the low proportion of global exploration investment coming to India cannot be said to be due to the low geological potential or low mineral prospectivity.

Country share in global exploration budget 2017

Country	%share in global exploration budget	Country	%share in global exploration budget
Canada	14%	West Africa	5%
Australia	13%	East Africa	2%
United States	7%	DR Congo	2%
Mexico	6%	South Africa	4%
Peru	6%	Russia	5%
Chile	6%	China	6%
Lat. America(rest)	6%	Pacific/South East Asia	5%
Brazil	4%	Former Soviet Union	1%
Europe	5%	Others (including India)	3%

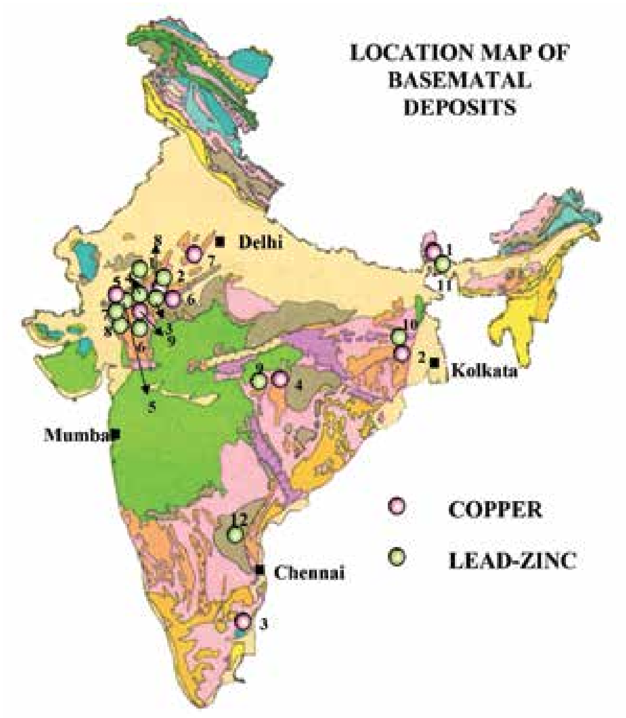
Source: Worldwide Mining Exploration Trends 2017, S&P Market Intelligence Data

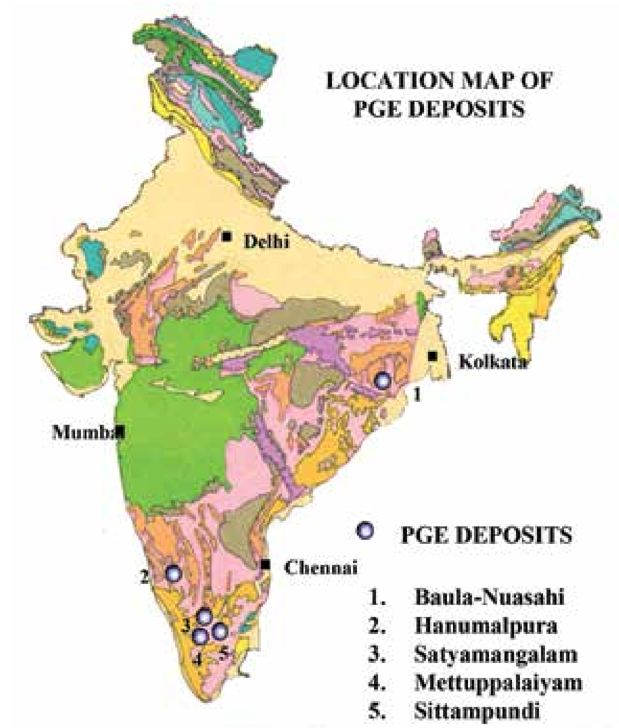
Commodity-wise expenditure on exploration

(US$ billion)

Year	Gold	Base metals (copper, nickel ,lead/zinc)	Diamond	PGM(platinum group of metals)	Other minerals	Total
2012	9.65 (47%)	6.57 (32%)	0.62 (3%)	0.31 (1.5%)	3.39 (16.5%)	20.53 (100%)
2013	6.64 (46%)	4.76 (33%)	0.58 (4%)	0.14 (1%)	2.31 (16%)	14.43 (100%)
2014	4.62 (43%)	3.76 (35%)	0.54 (5%)	0.21 (2%)	1.61 (15%)	10.74 (100%)
2015	4.14 (45%)	3.13 (34%)	0.46 (5%)	0.14 (1.5%)	1.33 (14.5%)	9.20 (100%)
2016	3.48 (50%)	2.16 (31%)	0.28 (4%)	0.070 (1%)	0.98 (14%)	6.97 (100%)
2017	4.05 (51%)	2.38 (30%)	0.25 (3%)	0.080 (1%)	1.19 (15%)	7.95 (100%)

Source: S&P Global Market Intelligence (For 2012–17)





Exploration as Part of the Larger Strategy of Mineral Development in India

Exploration is in fact the prime mover of mineral development; it is the exploration horse that pulls the mining cart. Though in ancient times mineral finds were mostly by accident, modern mining is mostly the result of scientific exploration by multi-disciplinary teams using the tools of physics, chemistry, and geology.

Evolution of Mineral Policy and Legislation in India

The Mines and Minerals (Development and Regulation) Act 1957 (MMDR Act) was enacted at a time when the public sector occupied the commanding heights of the economy. The National Mineral Policy 1993 was the first policy of the mineral sector, brought out soon after economic liberalization. It sought to encourage private investment in exploration and mining, and the sectoral legislation, the MMDR Act, was extensively amended as a consequence. However, investment in general and FDI in particular remained below expectations and a high-level Committee (also known as the Hoda Committee), was constituted for the purpose of reforming the mineral sector. The recommendations of the Hoda Committee led to the announcement of the National Mineral Policy 2008. The main thrust of the 2008 Policy, based on the Hoda Committee recommendations, is that:

- The private sector should be the main source of investment in reconnaissance and exploration. Reconnaissance should be made non-exclusive to attract more players.
- Exploration and mining will be recognized as independent activities with full transferability of concessions.
- The Concession grant system should be made seamless for the purpose of transiting from Reconnaissance Permit (RP) to Prospecting License (PL) to Mining Lease (ML) on a first-in-time basis in a time-bound manner with security of tenure.
- To specially incentivize high technology for discovery of deep seated deposits (of base metals, etc.), a new concession instrument called the Large Area Prospecting License (LAPL) should be introduced with the concessionaire systematically relinquishing area over the concession period, till at the end of the

concession he can get a ML over the remaining area capped as per the provisions of the Act.

Hoda committee also recommended that for minerals of a "bulk nature" such as iron ore, limestone, bauxite, etc., which are spread over relatively large areas close to the surface, in case the deposit is fully prospected (usually at public expense; also where a lease is relinquished or revoked after the lessee does exploration), the deposit may be auctioned. In other cases, the private sector may apply for RP/PL, etc., as the case may be on a first-in-time basis.

Based on this, a new MMDR Bill 2011 was introduced in Parliament with the above features as well as provisions relating to:

- Seamless transition, with full transferability
- New concession for Large Area Prospecting for deep seated minerals
- Auction of fully prospected deposits
- Creation of National, State and District Mineral Funds
- Creation of National and State level Mining Regulatory Authorities and Tribunals, etc.

However, the Bill lapsed on Dissolution of the Lok Sabha in May 2014.

Recent Changes to the Legislative Framework for Exploration

In 2015, the Mines and Minerals (Development and Regulation) Act 1957 (MMDR Act) was amended (and Rules were notified thereunder) with the intention of removing discretion and introducing more transparency in the allocation process. The following were the main changes in relation to grant of mineral concessions:

- Lease of existing mines used for captive purposes will be up to 2030 or end of current lease validity or 50 years from start of original lease, whichever is later, and at the end of the period the mine will be put out to auction. For non-captive mines, the end date is 2020 instead of 2030. (A summary of the number of mines likely to require auction in 2020 is available in Annexure 1).
- Fresh mineral concessions will be granted only on the basis of bidding, for the prospecting stage or mining stage depending on level of data (Section 10B(2) and 11(2), respectively). The Mineral (Auction) Rules 2015 notified under the MMDR Act specifies the auction procedures.
- The earlier process of granting Reconnaissance Permits on a first-come-first-served basis is replaced with a system of Non-Exclusive Reconnaissance Permits (NERP) (Section 10C, MMDR Act), but with no rights to proceed to prospecting or mining in case of evidence of mineralization. The Mineral (NERP) Rules 2015 issued under the Act specify the procedures. Section 10 C, which provides for the grant of the Permit, also states that a NERP holder shall have no right to claim for a prospecting license or a mining lease on the basis of his reconnaissance. The intention is that the data discovered in an NERP will be used to conduct further exploration by the government agencies so as to auction a mineral find. The NERP Rules 2015 states in Rule 4 (1) that the NERP holder can submit his data and ask the government to auction the find.
- Section 8A (2) now mandates that the mining lease would be a non-renewable 50-year lease, and at the end of the lease period the mine will be re-auctioned in case there are extractable reserves.
- The eligibility conditions required under the Mineral (Auction) Rules 2015, require a first-stage bidder (the entity incorporated in India) to have a net worth equal to 4% in case of a mining lease-stage bid (1% in the case of a prospect-stage bid) of the value of the estimated resources.
- The amendments made to the MMDR Act in 2015 provide for the creation of the National Mineral Exploration Trust (NMET) under Section 9C of the Act. The Trust is funded by a 2% cess on the royalty.

National Mineral Exploration Policy (NMEP) 2016

A National Mineral Exploration Policy (NMEP) has been brought out by the Government in 2016 to give further momentum to exploration efforts. The Policy purports to:

- Permit the engagement of private agencies to carry out exploration work in identified block/areas with the right to a certain share in the revenue (by way of a certain percentage of royalty/premium) accruing to State Government throughout the lease period, with transferable rights. The Policy states that this percentage/amount will be paid by the successful bidder to the concerned exploring agency and will be determined when mineral blocks on the basis of successful exploration are put on e-auction;

- Allow these exploration agencies to participate in e-auctioning when mineral blocks discovered on the basis of their exploration are put on auction; and
- Move towards working out normative cost of exploration for different kinds of minerals so that the exploration agencies could be compensated, in case they do not discover any mineable reserves in their respective areas.

National Mineral Policy 2019

The Government has recently issued the National Mineral Policy 2019; the main features distinguishing it from NMP 2008 include the following:

- Mineral production should feed into the "Make in India" initiative of the Central Government.
- States should auction mineral blocks with pre-embedded (environment and forest) clearances.
- The para heading "Survey and Exploration" is replaced by the words "Prospecting and Exploration".
- Private sector need not be the main source of investment in exploration, since the Policy only says "the private sector should be encouraged" to take up exploration.
- Exploration should be incentivized to attract private investments as well as state-of-the-art technology, within the ambit of the auction regime, through Right of First Refusal at the time of auction.
- The Policy also talks of seamless transition from Reconnaissance Permit to Prospecting License to Mining Leases or auctioning of composite Reconnaissance permit cum Prospecting License cum Mining Lease in virgin areas on revenue sharing basis or any other appropriate incentive as per international practice.
- The Policy conceptualizes a concept of "inter-generational equity" by saying:

  "For assessment of inter-generational equity in respect of each mineral, a disaggregated approach shall be adopted considering aspects like reserves/resources…. "(para 10 of the Policy).

SECTION 2: THE ISSUES

Transparency in Exploration and Mining

The amendments made in the MMDR Act in 2015 were mainly actuated by the desire to reduce undue discretion and arbitrariness in the allocation of concessions which are a source of potential corruption and to increase the revenue from the alienation of a public resource in favour of a private party. The main thrust of the amendment in 2015 was to auction mineral deposits for independent and transparent price discovery. By doing so, the law broke the traditional link between exploration and mining which governs private sector investment and is the international best practice. Since exploration is a high-risk venture, it was being compensated through a high-reward system of grant of the mining lease on payment of royalty. The normal process of grant was based on a "first-in-time"[3] criteria (since in most cases the exploration was of an area of unknown potential for minerals). By auctioning the mine, the law has left no incentive to the private sector to make huge investments in fresh exploration.

The Indian Bureau of Mines in its **Indian Minerals Yearbook 2018** (Part I: General Reviews): "Status of Reconnaissance Permits, Prospecting Licences and Mining Leases", reports the following for exploration and prospecting during the period 2015–18:

Prospecting Licences Granted, 2015–16 to 2017–18

State	2015–16		2016–17*		2017–18**	
	No.	Area (ha)	No.	Area(ha)	No.	Area(ha)
India	5	2869.04	-	-	-	-
Andhra Pradesh	1	900.00	-	-	-	-
Chhattisgarh	1	1548.00	-	-	-	-
Odisha	3	421.04	-	-	-	-

**Source: Bulletin of Mining Leases & Prospecting Licenses, 2017.*

***Source: Data received from various State Governments (Compiled the data from BMI April–September 2017 and BMI October 2017–March 2018).*

Reconnaissance Permits/Composite (PL cum ML) Licences[4]

RP/NERP			PL cum ML		
2015–16	2016–17	2017–18	2015–16	2016–17	2017–18
During 2015–16, no information regarding Reconnaissance Permits/ Non-Exclusive Reconnaissance Permits having been approved/ granted was received	During 2016–17, no information regarding Reconnaissance Permits/ Non-Exclusive Reconnaissance Permits having been approved/ granted was received	During the period from April 2017 to March 2018 no information regarding grant of Reconnaissance Permits/ Non-Exclusive reconnaissance Permits has been received	During 2015–16, no information regarding "Prospecting Licence-cum-Mining Lease" or "composite licence" having been approved/ granted was received	During 2016–17, no information regarding "Prospecting Licence-cum-Mining Lease" or "composite licence" having been approved/ granted was received	During the period from April 2017 to March 2018, no "Prospecting Licence-cum-Mining Lease" or "composite licence" has been approved/ granted

[3] *First-in-Time (FIT) is also called "First-come-First-Served" (FCFS). Details of the grant process in various mineral-rich countries is given in Annexure 3.*

[4] *Compiled from pages 3-2 and 3-3 of the Indian Minerals Yearbook, 2016, 2017 and 2018.*

It is interesting that the link between exploration and mining seems to be well understood by the Courts. The Supreme Court in its Opinion dated September 27, 2012 on a Reference by the President of India has stated, (Special Reference No.1 of 2012 under Article 143(1) of the Constitution of India), that auction is not the only way of discharging a public trust while alienating natural resources. As the Court has stated:

> *"Therefore, in conclusion, the submission that the mandate of Article 14 is that any disposal of a natural resource for commercial use must be for revenue maximization, and thus by auction, is based neither on law nor on logic…. besides legal logic, mandatory auction may be contrary to economic logic as well. Different resources may require different treatment. Very often, exploration and exploitation contracts are bundled together due to the requirement of heavy capital in the discovery of natural resources. A concern would risk undertaking such exploration and incur heavy costs only if it was assured utilization of the resource discovered; a prudent business venture, would not like to incur the high costs involved in exploration activities and then compete for that resource in an open auction."*

As has been anticipated by the Supreme Court, evident from the extract above, auctions have resulted in the potential for exploration investments being adversely impacted. While it may be argued that auctions at least enable independent and fair price discovery, the fact is that till exploration results reporting processes become transparent and credible in their own right, the valuation for auction purposes will always be subjective and prone to error.

Auctions can Still be Subjective and Non-Transparent

The current system of auctions of "mineral resources" under the MMDR Act (through the 2015 amendment) based on G2-level data for mining leases and G3-level data for Composite licenses (which corresponds to [332] and [333], respectively as per UNFC classification) has several potential problems arising out of the uncertainty of the estimations. As mentioned in paragraph 15.1 of the NMEP, the aim is to build a steady stream of auctionable prospects by funding State Governments through the NMET to produce G3- or G2-level reports. As a matter of fact, 332- and 333-level exploration is not enough to quantify an economically mineable or a potentially economically mineable reserve, and expert knowledge based on all the available evidence needs to be brought to bear to make a valuation for auction purposes, specifying the assumptions and projections. A prefeasibility report is essential in such circumstances, and in the interest of a level-playing field, the standard applied to the auction of mining leases should not be lower than that required for transiting from prospecting to mining under the non-auction (legacy case) provisions of the MMDR Act.

In any case, a more robust system of reporting of mineral resources needs to be used than the current UNFC system. There are systems like the Joint Ore Reserves Committee (JORC) code which require regular periodic reporting of exploration results and rely on credible third parties for assessments of the valuations based on feasibility.

Mineral Auctions Can Distort the Market

The MMDR Act as amended introduces the concept of "captive" and "non-captive" mining, which is a legacy of the coal sector where it is still prevalent because of the nationalization of coal mines. Many States may prefer to auction mines for captive purposes to help metal making companies within the State. However, the newly introduced segmentation will interfere with the operation of demand-supply signals based on market forces and result in sub-optimal use of resources, since the so-called "captive" mines are generally restricted from selling low grade ores (not usable in their own metal making units) and value-added intermediate products in the market.

But most importantly, by segmenting the market and creating a perception of resource scarcity, auctions for "captive" mines may lead to unnaturally aggressive auction bids by the metal makers (for fear of stranded assets) with every possibility of a "winners curse" given the volatility to which the market in this sector is subject.

The need to directly link a mine with a specific metal producing unit appears to be superfluous as a general principle, since most minerals can only be used to make metal (or the main constituent). If the intention is to ensure that minerals are used for national development by producing metals for manufacturing and infrastructure rather than say, for direct export, clearly restrictions at the export end would have been a better instrument than the concept of captive mining. Captive mines do give a sense of resource security to a metal maker if there is a general shortage or if the supply infrastructure is not in place and the metal making unit is the only entity capable of making investments for the purpose; but India is actually past that stage.

The amendment to the Act also creates a non-level playing field since Public Sector Undertakings (PSUs) are allocated mines without auction. Though the amendment does allow the States to receive a premium over and above royalty, the process is unclear. The Mineral (Mining by Government Company) Rules 2015 provides that a Government company or corporation or a joint venture, granted a mining lease, shall in each case, pay an additional amount equivalent to a percentage of the royalty as determined by the Central Government. Unless the additional amount is benchmarked to the auction premiums paid by the private sector, States may not be receptive to proposals for allocation of mines to Central PSUs, since it will mean foregoing revenues.

Effective Regulation

The MMDR Act as amended in 2015 has increased the range and scope of work of the Indian Bureau of Mines (IBM) and the State Directorates of Mining and Geology (by making auctions as the only mode of granting mineral concessions), particularly with regard to ensuring accuracy of mineral resource estimations and mineral reserve valuations, which are specialized activities requiring the development of credible and multi-disciplinary expertise. However, the IBM and the State Directorates need to be strengthened with manpower, equipment, and skillsets in order to be able to discharge their regulatory responsibilities. They also need to ensure that exploration takes place in accordance with the terms and conditions of the license and in the larger interest of promoting discovery and exploitation. The regulatory systems need to be provided with the necessary teeth through the legislative framework to make the sector more conducive to investment and technology flows. Capacity building for this purpose has to be a high priority if the intention behind adopting the auction route is to be realized.

Using NMET Funds Effectively

The NMET is funded from a 2% cess on royalty. Assuming an annual royalty flow of Rs 30,000 crore (including coal royalty) the funds accruing to the Trust will be of the order of Rs 600 crore per annum (or $100 million per annum). While this is much higher than the current spending level in the region of $5 million a year (mostly on coal exploration), this is clearly a drop in the ocean compared to the exploration expenditures in countries such as Canada (US$1110 million), Australia (US$ 1080 million per annum), and Latin America (US $800 million per annum).[5] It would appear that the Trust can cover only some of the huge expenditure that is entailed in stepping up the pace of exploration and may not be able to adequately capture the spirit of the high-risk high-reward paradigm.

The Trust funds are currently used to fund detailed exploration activities of the GSI, and Central PSUs including MECL. There is a danger that the Trust funds may take GSI away from its primary work of baseline surveys of geology, geophysics, and geochemistry into the quicksand of detailed exploration for minerals. There is also a distinct possibility that GSI, which post restructuring is inducting expert manpower, may not be able to muster the scientific personnel to conduct detailed exploration on a mass scale with the requisite expertise (as well as the experience), particularly for deeper deposits of base metals, noble metals, and gemstones. The entire strategy for exploration may actually need to be analysed further from the point of view of ensuring that GSI's work of baseline survey and mapping is not disrupted on the one hand, and funds and expert resources for exploration flow are unhindered on the other. The fact that the 2019 Policy has replaced "Survey and Exploration" with "Prospecting and Exploration" indicates that the fear may not be unfounded.

The intention of the Policy is that the preliminary work will be done by public agencies (and their private nominees) so that the data gathered can be used to auction any

[5] *See Annexure 2.*

mineral occurrences, and thus maximize revenues. The National Mineral Exploration Policy in paragraph 15.1 states that: "State Governments have a key role to play in building up a steady stream of auctionable mineral prospects. They will have to take up mineral exploration reports prepared by the GSI or other agencies and build on them to complete G3 or G2 level of exploration. States also need to build up the exploration capabilities of their staff. The Central Government will have to provide suitable incentives to expedite this process. Capacity building of States will be supported by the NMET."

Ensuring that mineral finds are explored to G3 or, better still, G2 levels require substantial ground-level work and expenditure, with the attendant risk of infructuous expenditure in case the find is not really exploitable for technical or commercial reasons. Currently, the capacity of these public agencies is severely limited in terms of geoscientific and technical resources. Substantial investments [including financial equity in the case of PSUs and budget support in other cases] will have to be made to build up capacity to conduct detailed exploration and efficiently use modern technology to locate concealed mineral deposits. Mineral exploration for concealed or deep-seated minerals also requires substantial multidisciplinary expertise that can only be built up over time. Appendix 3 gives details of some of the processes involved. Appendix 4 gives an indication of areas of the country with potential that can be explored (with varying levels of risk).

Though the Policy is still in the process of being rolled out there are clearly several issues that need deeper consideration:

- The exploration work of the private agencies is not covered by the current legislative framework which provides for an NERP. This may imply that the agencies will not be subject to the direct regulatory control of the IBM in terms of the Mineral (Concession) Rules 1960 and the Mineral (Conservation and Development) Rules 2017 (replacing the earlier Rules of 1988), as would be the case with a concessionaire.
- The provision that such agencies may also bid in the auction itself also raises many issues, including that of a level-playing field, as well as the true competitiveness of their bid for a revenue share which is the basis of their selection. The possibility that they may not share all the data in order to enjoy an advantage cannot be discounted.
- As already stated, the annual accrual into the National Mineral Exploration Trust is of the order of Rs 600 crore ($100 million); a significant proportion will be reserved for bringing prospects to G3 or G2 level through the GSI, Central Mine Planning and Design Institute (CMPDI), MECL and State Directorates of Mining and Geology. Capacity building of the States will also need to be undertaken out of Trust funds as mentioned in paragraph 15.1 of the NMEP. The amount available to fund private exploration from the Trust funds for exploration under the NMEP is, therefore, likely to be limited.
- Though the NMEP in paragraph 11.2 advocates the development of a mechanism by IBM to periodically fix national priorities for exploration, because of funds and capacity constraints, it is difficult to see a major expansion in exploration for deep-seated and concealed mineral deposits or for identified strategic or other minerals identified on the basis of a prioritization process. The public funds audit process of the CAG of India is unlikely to be enthusiastic about the NMET funds being used in "high-risk high-reward" situations, and what funds are available are likely to be applied for location of the low hanging fruit, i.e., surficial minerals.
- The world over, exploration is moving in a direction that allows for greater freedom and flexibility. In Canada, some Provinces incentivize high-risk exploration through partial subsidy. In Queensland, Australia for instance there is a move to give more operational flexibility to exploration agencies based on progressive accumulation of data. The NMEP by contrast reflects a model with high operational and financial control, which is not likely to attract world-class exploration expertise.

"Exploring in India" to "mine in India" to "Make in India"

As the country develops and industry and manufacturing grows, impelled by the **"Make in India"** policy, assured availability and proximity of mineral resources will play an important role in giving a competitive edge to the Indian industry in general and manufacturing in particular. Paragraph 11.2 of the NMEP contemplates that the IBM, while determining the national priorities for exploration, needs to make assessments with regard to India's long-term mineral security. In particular, emphasis needs to be given to the co-production of by-product metals from base metal ores through process R&D so that the country's needs of the so-called Technology Metals and Energy-Critical Metals are effectively met and provide raw material security on the one hand and a competitive edge on the other for the country's manufacturing sector. Exploration should not only increase revenues, but should also improve India's mineral security and competitive edge.

A study by The Council for Energy, Environment and Water (CEEW) titled "Critical Non-Fuel Mineral Resources for India's Manufacturing Sector: A Vision for 2030" states as follows:

"A clear understanding at the national level, of India's mineral resource base, is a prerequisite for any kind of strategic planning for resource security. Currently, less than 10% of India's total landmass has been geo-scientifically surveyed for an assessment of the underlying mineral wealth. This is a big deterrent for private exploration agencies to invest, as they require good base line data to justify risky investments. Further, the recently amended MMDR Act 2015 advocates for a transparent regime for the grant of mining leases, but certain provisions such as the non-exclusive reconnaissance permit act as deterrents to private investment. The expectation of returns when risk capital is employed is also high and provisions of royalty to RP holder (from the subsequent miner) are not seen as lucrative.

As recognized by the NMEP (2016), a prioritization of exploratory activities is essential to make best use of the limited amount of resources available with the government. The study (i.e., the CEEW study) proposes a useful decision-tree analysis, overlaid with indicators of criticality of specific mineral, which then provides a priority order for exploration efforts. This is not a definitive approach but also identifies interventions at other levels – trade, recycling or finding technical substitutes. The study also highlights minerals with low or no reserves in India, and the ones, which are available only as an associated, or by-product from other mineral processing. These include bismuth, cadmium, gallium, germanium, indium, molybdenum, rhenium, selenium and tin, and all require specific attention at the national level."

Clearly the paradigm for "Make in India" is one where exploration priorities are determined keeping in view the medium-term requirement for minerals and development of processes through R&D to ensure optimum extraction of those minerals and metals which are identified in the prefeasibility studies as requiring process R&D for their economic extraction. Currently, the sector is not organized towards private sector exploration, what to talk of process R&D. The world over, mineral deposit-specific process R&D is funded by the private sector mostly using venture capital. In Canada, Australia, and many other mineral jurisdictions, the highest risk, of the initial aerial reconnaissance and identification of potential areas based on geophysics is undertaken by so-called "Juniors", who are small entities consisting of professional geologists and geophysicists in most cases, who are funded by venture capital from exchanges such as the TSX Venture Exchange. These Juniors sell the data they acquire of promising mineralization to larger exploration companies who can take the exploration forward up to mining stage in case of promising finds. Juniors form an important component in the exploration ecosystem in terms of risk management, and receive significant funding as given below:

Year	No. of Junior Companies involved	Amount spent (US$ billion)	% increase/ decrease over last year
2012	3500	20.53	-
2013	3500	14.43	(-) 29.71
2014	2700	10.74	(-) 25.57
2015	3500	9.20	(-)14.34
2016	1580	6.97	(-) 24.24
2017	1535	7.95	14.06

Source: S&P Global Market Intelligence (For 2012-17)

While the National Mineral Policy 2008 recognized the strengths of the model, the auction process incorporated in the MMDR Act in 2015 now makes it impossible.

Another, distinct aspect is that "Make in India" does require Indian industry to be globally competitive. Auction not only disincentivizes exploration, it also impacts on the metal makers profit margins, with the possibility of operating losses or reduced competitiveness and consequent imposition of import barriers. Royalties (including the auction premium), imposts and costs need to be internationally benchmarked if the objective of "Make in India "is to be realized.

Intergenerational Equity

The NMP 2019 states: *"There is a need to understand that natural resources, including minerals, are a shared inheritance where the state is the trustee on behalf of the people to ensure that future generations receive the benefit of inheritance. State Governments will endeavour to ensure that the full value of the extracted minerals is received by the State. However, for assessment of inter-generational equity in respect of each mineral, a disaggregated approach shall be adopted considering aspects like reserves/resources and potential for reuse through recycling, which are relevant and suitable in the Indian context."*

This is in sharp contradistinction to the National Mineral Policy 2008, which stated that *"Conservation of minerals shall be construed not in the restrictive sense of abstinence from consumption or preservation for use in the distant future but as a positive concept leading to augmentation of reserve base through improvement in mining methods, beneficiation and utilisation of low grade ore and rejects and recovery of associated minerals."*

The issue is of utmost importance for our economic development. If mineral production is to be regulated in the manner given in NMP 2019 on the one hand, and our resource base grows slowly because of poor private sector participation in exploration (for reasons already elaborated), the implications for any "Make in India" initiative is serious. The same applies to the potential for exports. It is important that the right approach is adopted and the private sector is fully incentivized in mining and exploration as well as process R&D to be able to continuously feed industry and other consuming sectors and help attain a higher stage of inter-generational equity.

SECTION 3: CONCLUSIONS AND THE WAY FORWARD

- **"Make in India" requires reliable access to raw materials including mineral resources.** Continuous exploration to locate new mineral deposits with regularity for addition to our reserves/resources is the key to mineral resource security as well as our growth prospects. Mineral concession systems must start by optimizing this end of the process.
- **Exploration, particularly for deep seated minerals, is a high-risk enterprise.** The world over, such exploration is driven by private venture capital and scarce public resources are mainly used to generate pre-competitive data in the form of geoscientific surveys and maps.
- **Open up exploration for private investment:** To ensure that the government gets the best value for its known natural resources, the provision of "reservation" of areas, already available in the MMDR Act, can be used to keep out of the purview of the private sector areas that are sought to be taken up, say in the next 5 to 10 years for a detailed exploration with a view to auction or allocation to the public sector. The remaining areas may be left open to exploration investment by the private sector with assured rights of mining as is the best international practice.[6]
- **Specialized venture capital-based exploration companies need to be incentivized** to do deep exploration using advanced technologies. This includes the "Juniors" who form a crucial part of the exploration ecosystem relating to the "high-risk high-reward" space. The amendment to the MMDR Act introducing an "auctions only" system has prevented their participation by delinking exploration from mining; moreover, the Mineral (Auction) Rules thereunder practically render the Juniors ineligible to bid even for the PL stage.
- **Introduction of the "Large Area Prospecting License (LAPL)" is clearly necessary,** specifically for minerals other than iron ore, bauxite, limestone, etc., (bulk or surficial minerals) and for deep exploration, with provision for a separate channel that allows the LAPL concessionaire to claim assured and direct mining rights (including transferability thereof). This alone will ensure that the private sector investments flow into exploration along with new and advanced technology to locate deep and concealed minerals vital for India's economic growth and development, and for its long-term minerals security.
- **The Non-Exclusive Reconnaissance Permit (NERP) with the right to proceed to PL and ML** on a non-discretionary first-in-time basis, together with the LAPL mentioned above, can enable the location of new mineral resources, and must be the main route for mineral discoveries.
- **The auction system should be used for fully prospected deposits only,**[7] and without any distinction between captive and non-captive mines, so that a free market for ores develops and the resources are used most efficiently taking into account market forces. This will also make the environment and forest clearances easier to negotiate. In the case of the public sector the operative principle should be "allocation" of a mine rather than grant of a captive resource. This will enable the public sector to freely sell surpluses or value-added products or non-usable grades in the open market.
- **Allow extension and transferability of mineral concessions:** Such mines as are auctioned should be allowed to be worked through extension after every 20 or 30 years till exhaustion of the economically mineable portion of the deposit. This will ensure stability of tenure and enable the concessionaire to do long-term investment and mine planning and make best use of the grades. Side by side with this principle, there needs to be the principle of "full transferability" of a mine, in line with international practice which encourages mergers and acquisitions to drive efficiency.
- **The adoption of a robust and more transparent exploration data reporting,** such as the Internationally recognized JORC Code or its equivalent is an urgent necessity to make the auction process in

[6] *See Annexure 3*

[7] *See Annexure 4 for a World Bank expert view on the issue.*

India more reliable, credible, transparent, equitable, and investment friendly. This is particularly important if private agencies are engaged, as proposed under the NMEP, to explore prospects using NMET funds, and all the more so if they are to share the revenue stream and even participate in the auction itself. The JORC process would involve regular public reporting of Exploration Results and the estimation and valuations by "Competent Persons" who will be independent third parties.

- **The National Mineral Exploration Trust must be used strategically and with discretion,** only where there is a definite public interest, e.g., Technology Metals and Energy Critical Metals are likely as byproducts. The process of deciding on investment priorities must flow from Para 11.2 of the NMEP which mandates IBM to periodically fix national priorities for exploration.
- **A sensible balance must be struck between GSI's survey activities and exploration**; baseline data which produces pre-competitive data of immense value for increasing our resource cum reserve base is of long-term importance and should not be ignored.
- **The time has come to create independent Mining Regulatory Authorities and Tribunals** to address the complex and widespread nature of regulatory deficit generally in the mining sector, (the latter replacing the in-house "revision " mechanism under section 30 of the Act) for oversight at Central and State level. This can restore investor confidence and ensure that the primary regulatory mechanisms for exploration (as well as mining plans and closure plans) operate transparently and reliably to internationally recognized technical standards.
- **Inter-generational equity should be seen not as a negative concept** to ration out the known reserves over the generations, but as a positive concept to increase the resource base, with sequestration of part of the revenue stream from production for use by future generations. On the one hand, GSI's survey activities and LAPL data are critical to understand the potential resource base and need to be prioritized. On the other, the funds flowing into the District Mineral Funds need to be tapped to sequester a portion for creation of Wealth Funds to be used to address inter-generational equity.

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Material in Appendices 2 to 4 draw upon the following documents:

1. Location and Development of deepseated metalliferous Deposits in India -Centre for Techno-Economic Mineral Policy Options(C-TEMPO), Ministry of Mines (January 2011)
2. New Insights on Mineral Exploration Concepts and Guidelines Geological Survey of India, Ministry of Mines (February 2018)

ANNEXURE 1

State-wise leases which are due to expire by 2020

S No.	State	Working Mines	Non-Working Mines	Total Mines	Total Auctionable Mines
1	Andhra Pradesh	3	6	9	9
2	Goa	0	184	184	NA
3	Gujarat	5	6	11	7
4	Himachal Pradesh	1	1	2	2
5	Jharkhand	5	16	21	18
6	Karnataka	8	42	50	33
7	Madhya Pradesh	1	12	13	2
8	Maharashtra	0	9	9	NA
9	Odisha	24	7	31	31
10	Rajasthan	2	2	4	2
Total		49	285	334	104

Source: Ministry of Mines. https://mines.gov.in/writereaddata/UploadFile/ccec01102018.pdf

ANNEXURE 2

Country-wise exploration expenditure

Country	2013	2014	2015	2016	2017
Canada	1.88	1.51	1.28	0.96	1.11
Australia	1.88	1.30	1.09	0.90	1.08
China	0.57	0.70	0.54	0.41	0.40
Peru	0.72	0.54	0.54	0.41	0.56
Brazil	0.04	0.30	0.27	0.28	0.24
Global	14.43	10.74	9.20	6.97	7.95

Note: India's exploration expenditure for the financial years 2016, 2017 and 2018 was USD 0.13, 0.15 and 0.17 billion, respectively. This comprises of expenditures incurred by GSI, MECL, and NMET only. In addition, CMPDIL, Department of Atomic Energy and State DMGs also incur significant expenditure on exploration.

Source: 1) S&P Global Market Intelligence, 2018

2) For India: Ministry of Mines

ANNEXURE 3

Mode of Grant of Mineral Concessions in various jurisdictions

S.No	Country	Mode of Grant	Initial Mining Lease Tenure	Renewal Provision
1	Argentina	FCFS	Till Mineral Exhaustion	—
2	Bolivia	FCFS	30 years	30 years
3	Botswana	FCFS	25 years	25 years
4	Brazil	FCFS	Till Mineral Exhaustion	—
5	Canada	FCFS	20 years	10 years
6	Chile	FCFS	Till Mineral Exhaustion	—
7	Colombia	FCFS	30 years	30 years
8	Ghana	FCFS	30 years	30 years
9	Mexico	FCFS	50 years	50 years
10	Namibia	FCFS	25 years	15 years
11	Peru	FCFS	30 years	Extension on request
12	USA	FCFS	Till Mineral Exhaustion	—
13	South Africa	FCFS	30 years	30 years
14	South Australia	FCFS	21 years	21 years
15	West Australia	FCFS	21 years	21 years
16	Mongolia	FCFS	30 years	20 years for two successive periods
17	Mauritania	FCFS	30 years	Not available
18	Morocco	FCFS	10 years	10 years
19	Mozambique	FCFS	25 years	25 years
20	China	– FCFS for unexplored areas – Auction for already explored areas	– 30/20/10 years for large / medium/small mines	Extension on request
21	Indonesia	Auction	– 20/10 years for metallic/non-metallic minerals	Renewal tenure varies for different minerals
22	Russia	Auction	25 years	Extension on request
23	India	Auction	50 years	No Renewal

FCFS=First Come First Served

Source: FIMI

ANNEXURE 4*

Mineral Resource Tenders and Mining Infrastructure Development

by Michael Stanley and Ekaterina Mikhaylova

Extracts from Chapter 2: Award of Mineral Rights

The award of mineral rights for exploration and/or exploitation follows one of two principal processes: open mineral access (first-come, first-served principle) and competitive resource tender....

The process selected will depend on the type of mineral commodity, the level of information available for the resource and deposit type (strata-bound deposits versus those placed in varying host stratigraphy), and the amount of potential investor interest at the time of award....

Open Mineral Access

When relatively little is known about the resource endowment[8] and there is no competition for the deposit, many successful mining countries—such as Australia, the United States, various Latin American nations, and now quite a few African countries—employ the open mineral access (first-come, first-served) process. Under this approach, license holders have time-bound access to license areas. Award provisions encourage the turnaround of exploration properties. For example, binding work programs, mandatory surrender of part of the licensed area, and/or increased land rental fees over time ensure that companies expedite exploration work and surrender those areas they do not find suitable so as to enable other companies to obtain the exploration data and express their interest in the area or deposit.

Open mineral access has been successful in attracting prospecting over large search areas and has ultimately led to exploration holdings (licenses) over smaller areas of more prospective ground. ….

Competitive Tender

The second approach—the competitive tender—largely presumes a greater knowledge of the mineral potential (either from earlier exploration or mining activities, or the recognition that some minerals are likely to be found in particular geologic formations) and an increased demand for rights as evidenced by the existence of several companies interested in applying for the same license area.

The rights to many bulk commodity minerals (such as iron ore), coal, industrial minerals (such as phosphate), and construction minerals are sometimes assigned through resource tenders or concession leases. This has much to do with the strata-bound nature of the deposits. Once the presence of a deposit is verified on a mineral holding, there is, by geological extrapolation, a higher probability of discovery for adjoining resources should they occur within the same stratigraphy and with similar geological characteristics. A competitive licensing process or systematic leasing of concessions sets the requirements and standards higher to limit license applications to more technically and financially qualified investors rather than leave the door open to any individual or company that could have obtained such licenses through open access.

In some cases, an open mineral access license granted for a particular mineral prospect (a hidden deposit) is relinquished or revoked through regulatory action. A government might then want to take the opportunity to shift to a resource tender to competitively reassign the mineral right.

This shift is possible when previous exploration efforts have yielded sufficient information about the quantity and quality of the resource asset that a subsequent investor will enjoy appreciably reduced discovery risk. When this situation arises, the government may obtain a share of the resource rent up front in exchange for the information provided along with the mineral rights.

**World Bank: Extractive Industries For Development Series #22(Sept 2011);*

[8] This may be the case for "hidden deposits." Metallic minerals, both precious and base metals, are generally considered to be hidden deposits in that they occur at depth and are less likely to have a surface expression. Thus, without the aid of expensive sensing technologies, little is known about the underlying resource potential. (the footnote is part of the original text).

APPENDIX 1

Glossary of Technical Terms

Aero-EM: Airborne electromagnetic (EM) surveying is an active method to measure the electrical conductivity of the rocks. This gives a better idea of the Earth's structure and the arrangement of deposits at depth. The survey requires a source of EM field, which is generated using a large transmitter coil, fixed onto a helicopter or a light fixed-wing aircraft. There is also a "receiver" on board, which measures the EM response. During the survey, the aircraft needs to fly as close to the ground as possible to get more signal back from the Earth, although regulatory and safety issues come into play here when it comes to the practicality of what's permitted and what's not. The survey is carried out by flying in parallel lines as it helps with the processing of the data.

Aero-magnetic survey: In an aero-magnetic survey, an onboard magnetometer measures and records the total intensity of the magnetic field at the sensor. The resulting aeromagnetic map shows the spatial distribution and relative abundance of magnetic minerals (most commonly the iron oxide mineral magnetite) in the upper levels of the Earth's crust. Because the rock types differ in their content of magnetic minerals, the magnetic map allows a visualization of the geological structure of the upper crust in the subsurface, particularly the spatial geometry of bodies of rock and the presence of faults and folds. Aeromagnetic data is commonly expressed as thematic (coloured) and shaded computer generated pseudo-topography images. The apparent hills, ridges, and valleys are referred to as aeromagnetic anomalies. A geophysicist can use mathematical modelling to infer the shape, depth, and properties of the rock bodies responsible for the anomalies.

Aero-Radiometric survey: The radiometric, or gamma-ray spectrometric method is a geophysical process used to estimate concentrations of potassium, uranium, and thorium by measuring the gamma-rays which the radioactive isotopes of these elements emit during radioactive decay. Airborne gamma-ray spectrometric surveys estimate the concentrations of the elements at the Earth's surface by measuring the gamma radiation above the ground from low-flying aircraft or helicopters.

Airborne Gravity survey: Gravity gradiometry is used by oil and mineral prospectors to measure the density of the subsurface, effectively by measuring the rate of change of gravitational acceleration due to underlying rock properties. From this information, it is possible to build a picture of subsurface anomalies which can then be used to more accurately target oil, gas, and mineral deposits. It is also used for determining water depth. The gravity gradiometer is mounted on an aircraft and flown over the survey area to obtain the gravity gradient measurements. The survey is typically flown at an altitude of 80 m or greater with a line spacing dependent on the target of investigation. The signature from buried sources (such as ore bodies) is maximized closer to the Earth surface and a low flying altitude is desirable.

Basement rock: Basement rock is the thick foundation of ancient metamorphic and igneous rocks often in the form of granite, that forms the underlying layer of continents.

Beneficiation: Beneficiation is the processing of minerals or ores for the purpose of (i) regulating the size of a desired mineral produce; (ii) removing unwanted constituents; and (iii) improving quality, purity, or assay grade of the desired mineral.

"Bulk" and near-surface minerals: Minerals occur through a variety of processes. Some minerals are formed by sedimentary processes and are deposited in basins which occur at the Earth's surface. These include limestone and some kinds of iron ore deposits. Some minerals such as Bauxite are formed by weathering processes. Such minerals generally occupy large surface areas and are often called "bulk" minerals. Very often they are available at or near the surface.

Chalcophile elements are those elements which have a strong affinity for sulphur; such elements concentrate in sulphides and are typical of the Earth's mantle rather than its core. Typical chalcophile elements are Cu, Zn, Pb, As, and Sb. In contrast, **Lithophile** elements are those with a strong affinity for oxygen. They occur as oxides, and especially in the silicate minerals which make up 99% of the crust. Examples of lithophile elements are Al, Ti, Ba, Na, K, Mn, Fe, Ca, and Mg.

Concealed, deep-seated, or deep-located deposits: Mineralization often occurs at depth, with no apparent surface shows. In other cases, mineralization, even if extensive, is hidden by subsequent sedimentary layers ("cover sediments"), or concealed by lava flows as in the case of the Deccan Trap areas. Deep seated minerals are formed under high pressure and temperature, and in many cases, through the chemical action of hot mineralizing fluids (hydrothermal action) associated with volcanism or tectonism. These minerals, including base metals such as copper, and noble metals such as gold, and special cases such as diamonds can occur at considerable depths.

Co-production of minor metals: Minor metals (including the so-called Energy Critical Metals) are not naturally found in concentration high enough to be profitably mined for their own sake. Many of them also occur in association with other metals which can be commercially mined (primary or major metals, such as lead-zinc-copper or gold or aluminum). Such associated minor metals can be recovered as by-products from the "waste" generated during the extraction of the major metals. Many minor metals are finding applications in renewable energy or electronics and though used in small quantities, can be quite critical. 'Major' minors include tungsten, cobalt, titanium, magnesium, where several hundred thousand tonnes are produced annually. Their production requires "process research" so as to put in place an ore-specific combination of physical and chemical processes to separate them from other material. There can be substantial risks and technical- and economic-feasibility questions associated with process research.

Crust: The continental crust is the layer of igneous, sedimentary, and metamorphic rocks that forms the continents and the adjoining areas of shallow seabed known as continental shelves.

Cratons are the old and stable parts of the crust (and the uppermost mantle), which having survived cycles of merging and rifting of continents, are distinct formations composed of ancient basement rock, often covered by younger sedimentary rocks. The Indian Craton is made up of the Aravalli Craton, Bundelkand Craton (granite-gneissic complex), Dharwar Craton, Singhbhum Craton, and the Bastar Craton.

Deccan trap: The Deccan traps are a large igneous province located on the Deccan Plateau of west-central India. They are one of the largest volcanic features on Earth. They consist of multiple layers of solidified flood basalt that together are more than 2000 m thick and cover an area of 500,000 km2. The bulk of the volcanic eruption occurred at the Western Ghats some 66 million years ago. This series of eruptions may have lasted fewer than 30,000 years.

Exploration

General Exploration involves the initial delineation of an identified mineral occurrence warranting further studies. Methods used include surface mapping, widely spaced sampling, trenching, and drilling for preliminary evaluation of mineral quantity and quality (including mineralogical tests on laboratory scale if required), and limited interpolation based on indirect methods of investigation. The objective is to establish the main geological features of a deposit, thereby giving a reasonable indication of continuity and providing an initial estimate of size, shape, structure, and grade. The degree of accuracy should be sufficient for deciding whether a Prefeasibility Study and a Detailed Exploration are warranted.

Detailed Exploration involves the detailed three-dimensional delineation of a known mineral deposit through sampling from outcrops, trenches, boreholes, shafts, and tunnels. Sampling grids for drilling are closely spaced such that size, shape, structure, grade, and other relevant characteristics of the deposit are established with a high degree of accuracy. Processing tests involving bulk sampling may be required.

Geoscientific survey and mapping is to be distinguished from "mineral exploration"; while the latter is specifically aimed at finding minerals, geoscientific surveys have a multitude of applications including subsurface water resource location and estimation; identifying potential geo-hazards such as landslides; the nature of rocks and soils; and understanding the topography and climate of the distant past. Very often, mineral exploration ventures use geoscientific surveys as a starting point for the identification of a target area for exploration.

Hydrothermal mineral deposit is any concentration of metallic minerals formed by the precipitation of solids from hot mineral-laden water (hydrothermal solution). The solutions are thought to arise in most cases from the action of deeply circulating water heated by magma. Hydrothermal mineral deposits are further classified as hypothermal, mesothermal, epithermal, and telethermal according to the temperature of formation, which roughly correlates with particular mineralizing fluids, mineral associations, and structural styles.

Intrusive or plutonic igneous rocks form when magma cools slowly below the Earth's surface. They are called intrusive igneous rocks if the magma has intruded into pre-exiting rock layers. Most intrusive rocks have large, well-formed crystals. Examples include granite, gabbro, diorite, and dunite. Igneous rocks are generally granites or basalts. The difference between **granites and basalts** is in their silica content (a basalt is about 53% SiO2, whereas granite is 73%), and in their rates of cooling.

IOCG: Iron Oxide hosted Copper Gold deposits

Laterite: A rock type rich in iron and aluminium; commonly considered to have formed in hot and wet tropical areas by intensive and prolonged weathering.

Leaching is the loss or extraction of certain materials from a carrier into a liquid (usually, but not always a solvent).

Low grade ores: the grade of the ore generally refers to the concentration of the mineral of interest in the mineral ore. As the grade drops, the economic viability of a mining enterprise also drops. When the grade of the ore is such that the economic viability is a significant risk, the ore is generally said to be of "low grade".

Mafic: a rock that is rich in Magnesium and iron (Ferric). Ultramafic rocks are igneous and meta-igneous rocks with a very low silica content (less than 45%), generally >18% MgO, high FeO, low potassium, and are composed of usually greater than 90% mafic minerals (dark coloured, high magnesium and iron content). The Earth's mantle is composed of ultramafic rocks.

Magma is molten rock stored inside the Earth's crust. Lava is magma that reaches the surface of the earth through a volcano vent.

Magnetotellurics (MT) is an electromagnetic geophysical method for inferring the Earth's subsurface electrical conductivity from measurements of natural geomagnetic and geoelectric field variation at the Earth's surface. Investigation depth ranges from 300 m below ground by recording higher frequencies down to 10,000 m or deeper. MT is used for various base metals (e.g., nickel) and precious metals exploration, as well as for kimberlite mapping. Audio-magnetotellurics (AMT) is a higher-frequency magnetotelluric technique for shallower investigations.

Metalliferous: meaning yielding metal; from *metallum* metal + *ferre* to bear (Latin).

Metallogeny is the study of the genesis and distribution of mineral deposits

Metasomatism is the chemical alteration of a rock by hydrothermal and other fluids.

Mineral: A mineral is a naturally occurring substance (generally inorganic, though coal is an organic mineral) that is solid and is representable by a chemical formula. It has an ordered atomic structure. It is different from a rock, which can be an aggregate of minerals or non-minerals and does not have a specific chemical composition. Most but not all minerals are crystalline; also, most but not all minerals have one or more metals as constituents.

Mineral resource: A mineral resource is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade, or quality and quantity that there are reasonable prospects for eventual economic extraction.

Mineral reserve (or Ore Reserve): A mineral reserve or an ore reserve is the economically mineable part of a mineral resource.

Mineral ore: An ore is a type of rock or rocky material that contains sufficient minerals with important elements including metals that can be economically extracted from the rock through mining operations. An ore body is the assemblage of such a rocky material.

Mineralization: Mineralization is the process of formation of a mineral out of unmineralized material or a concentration of the mineral above its normal abundance due to geological processes involving heat, pressure, chemical action, sedimentation, etc.

Mineral occurrence: This is an indication of mineralization that is worthy of further investigation. The term "mineral occurrence" only indicates the presence of one or more minerals but does not imply any measure of volume or tonnage, grade or quality and is thus not a part of a mineral resource yet.

Mineral deposit: A mineral occurrence of relatively higher concentration, of economic value.

Mining operation: A mining operation is any operation undertaken for the purpose of winning (i.e., recovering) any mineral. It generally includes extracting the ore and then processing it to recover the minerals in the ore.

Mining lease: A lease granted over a limited area for the purpose of undertaking mining operations.

Mining Tenement System: Such a system depicts the location, extent, nature, and status of current mineral concessions ("tenements"), and often allows for applications to be made for the grant of mineral concessions in areas not already covered. Sometimes the system also shows pending applications as well. The system may also show land ownership ("cadastre") and other legal information, such as officially notified forests or ecologically sensitive areas, for the benefit of intending applicants.

Orogen: An orogen or orogenic belt develops when a continental plate crumples and is pushed upwards to form one or more mountain ranges; this involves a series of geological processes collectively called orogenesis or orogeny. Orogeny is the primary mechanism by which mountains are built on continents. The Himalayas, which stretch over 2400 km are the result of an ongoing orogeny (the Himalayan Orogeny) — the result of a collision of the continental crust of two tectonic plates: the Indian and Eurasian continental plates.

A **placer deposit** or **placer** is an accumulation of heavier minerals by gravity separation from a specific source rock during sedimentary processes, e.g., river or sea wave action. The name is from the Spanish word placer, meaning "alluvial sand"

Paleo-placers: Placer deposits caused by ancient (paleo) processes no more in operation, e.g., geologically ancient river or sea no longer in existence.

A **Pegmatite** is an igneous rock, formed underground, with large interlocking crystals. Most pegmatites are composed of quartz, feldspar, and mica.

Petrology is the branch of geology that studies rocks and the conditions under which they form.

Porphyry is a textural term for an igneous rock consisting of large-grained crystals such as feldspar or quartz. Porphyry deposits are formed when a column of rising magma is cooled in two stages. In the first stage, the magma is cooled slowly deep in the crust, creating the large crystal grains. In the second and final stage, the magma is cooled rapidly at relatively shallow depth or as it erupts from a volcano.

Prospecting: Is any operation undertaken for the purpose of exploring, locating, or proving a mineral deposit, including geochemical and geophysical surveys, and drilling.

It is the systematic process of searching for a mineral deposit by narrowing down areas of promising enhanced mineral potential. The methods utilized are outcrop identification, geological mapping, and indirect methods, such as geophysical and geochemical studies. Limited trenching, drilling, and sampling may be carried out. The objective is to identify a deposit which will be the target for further exploration. Estimates of quantities are inferred, based on the interpretation of geological, geophysical, and geochemical results.

A Prospecting Licence granted under the MMDR Act permits general exploration as well as detailed exploration.

Proterozoic is a geological eon spanning the time from the appearance of oxygen in Earth's atmosphere to just before the proliferation of complex life (such as trilobites or corals) on the Earth. The Proterozoic Eon extended from 2500 mya to 541 mya (million years ago).

Prospectivity for minerals: This is a general assessment of the likelihood of finding minerals, based on the geological evolutionary history and geological set up (lithological, structural, and geomorphological) and geophysical, aeromagnetic, gravity, and radiometric imagery data sets.

Reconnaissance: Any operations undertaken for the preliminary prospecting of a mineral through regional, aerial, geophysical, or geochemical surveys and geological mapping, but does not include pitting, trenching, drilling, or sub-surface excavation.

A reconnaissance study identifies areas of enhanced mineralization on a regional scale based primarily on results of regional geological studies, regional geological mapping, airborne and indirect methods, preliminary field inspection, as well as geological inference and extrapolation. The objective is to identify mineralized areas worthy of further investigation towards mineral deposit identification. Estimates of the quantities should only be made if sufficient data is available.

Shield: A shield is a cratonic area where the basement rocks are exposed. It is a relatively flat region since mountain building, faulting, and other tectonic processes are greatly diminished. The age of these rocks is greater than 570 million years and sometimes date back 2000 to 3500 million years. The Indian shield consists of the Dharwar craton, the Southern Granulite Terrain (SGT) of Tamil Nadu - Kerala, the Eastern Ghat Mobile Belt (EGMB) along the east coast; and the intra-cratonic "Purana" basins.

Stratigraphy is the study of rock layers (strata) and layering (stratification). It is primarily used in the study of sedimentary and layered rocks, primarily to estimate the age of the various layers.

Supergene enrichment are processes that occur relatively near the surface (as opposed to deep hypogene processes). Supergene processes include the predominance of meteoric water (e.g., rainwater) circulation with concomitant oxidation and chemical weathering.

Unconformity: An unconformity is a surface of hiatus between successive strata representing a missing interval in the geologic record of time, produced either by an interruption in deposition or by erosion (by wind or water). An unconformity is a type of discontinuity due to an intervening period of geological activity for which the strata have no direct record.

Volcanogenic massive sulfide deposits, also known as VMS deposits, are a type of metal sulfide ore deposit, mainly copper-zinc which are created by volcanic-associated hydrothermal events in submarine environments.

Winner's Curse: The winner's curse is a phenomenon that may occur in "highest bid" auctions in conditions of incomplete information. In such an auction, the winner will tend to overpay as he is after all paying what his competitors felt was not worth it since they stopped at a lower bid.

APPENDIX 2

Genesis and Classification of Mineral Deposits

An ore or mineral deposit represents a geochemically anomalous concentration of elements in a very limited sector of the crust. Geological processes causing crustal growth and churning of the Earth's material lead to elemental concentration and formation of deposits. The crustal elements have to undergo enrichment up to several orders to attain the status of an economically minable deposit. The genesis of economic deposits is therefore, essentially a matter of sufficient enrichment.

Ore deposits are usually classified by the ore forming geological processes and the geological setting. But they rarely fit snugly into the boxes in which geologists wish to place them. Many deposits may be formed by more than one of the basic genetic processes described below. The following is a common categorization of mineral enrichment and deposit formation; examples of deposits are given in some cases in parenthesis:

1. **Deposits produced by chemical processes of concentration of elevated temperature within the Earth or at the sea floor.**

In magmas (Magmatic Deposits)

- By concentration of crystals from magma (chromite and magnetite of Bushveld complex, South Africa)
- By separation of immiscible sulphide or oxide liquids from magma (Cu-Ni at Sudbury, Ti at Allard Lake, Quebec)
- By crystallization of unusual magmas
  - ◊ Carbonatites (Nb at Aka, Onebee.; Cu and Phosphate at Palabora, South Africa)
  - ◊ Pegmatites (Nb-Ta in Nigeria; mica at Petaca, New Mexico, USA; Li at Kings Mtn, N, Carolina, USA)

From hot aqueous fluid formed within the Earth (hydrothermal deposits)

- Deposited within the Earth and associated with intrusive igneous bodies or volcanic centres
  - ◊ Disseminated sulphides in and adjacent to igneous bodies (porphyry.- CuMo deposits of Bingham, Utah, USA)
  - ◊ Contact metasomatic replacement of carbonate rocks (skarn[9] deposits of Fe at Iron Springs, Utah USA; Cu-Pb-Zn at Central District, New Mexico)
  - ◊ Vein and replacement deposits
    - In and adjacent to granitic intrusions (Sn-Cu at Cornwall, England)
    - Peripheral to granitic intrusions (Cu at Magma, Arizona, USA; Pb-Zn, Ag of Central District, New Mexico, USA; Pb-Ag of Cocur d' Alene, Idaho, USA)
    - Associated with volcanic centres and hot spring system on land (Ag at Pachuca, Mexico; Au at Carlin, Nevada, USA)
    - Cu associated with basaltic volcanism (northern Michigan Cu, Michigan, USA)

Deposited within the Earth but with no obvious relation to igneous activity

- Pb-Zn sulphide deposits in carbonate rocks (Mississippi Valley deposits, USA.) Udeposits in sandstones (Colorado Plateau, USA)
- Cu deposits associated with red sediments (Nacimiento, New Mexico and WhitePine, Michigan)

Deposited on the sea floor by fluids from hot springs

- Massive Fe-sulphides with base and precious metals, in association with volcanism (volcanogenic massive sulphides, Kuroko deposits, Japan)
- Base-metal sulphides unrelated to volcanism (Cu at Ducktown, Tennessee USA)
- Extensive Fe- and Mn-rich deposits with associated Au and other metals (as in pre-metamorphic carbonate beds at Homestake, S. Dakota, USA)
- By regional or dynamic metamorphism
  - ◊ By redistribution of chemical constituents (talc and tremolite deposits, concentration of Au at Homestake, S. Dakota, USA)
  - ◊ By recrystallization (garnet, kyanite)

[9] *Lime-bearing siliceous rock produced by the metamorphic alteration of limestone or dolomite*

2. **Deposits formed by chemical processes of concentration at or near the surface of the Earth at low temperatures.**

By weathering and related processes on land

- By leaching of soluble constituents to leave residual concentrations (bauxite, Fe-, Mn-, and Ni-rich laterites)
- By supergene enrichment of sulfides (Cu at Miami, Arizona, USA)
- By evaporation of pore waters from soil (U in caliche[10] at Yeelerie, Australia)

By precipitation in lakes and oceans

- By evaporation of water (evaporites, gypsum, halite, borates)
- By chemical changes in solution
- Precipitation of limestones and dolomites
- Unusual precipitates (Fe formation, Mn nodules, phosphates, basemetal sulphides)
- By biological processes and diagenesis
  - ◊ Accumulation of plant debris (e.g., coal)
  - ◊ Formation of liquid and gaseous products from plant and animal debris (oil and gas deposits)
  - ◊ Conversion of sulphates to native sulphur (sulphur deposits)

3. **Deposits produced by mechanical processes of concentration**

- Concentration by size in flowing water (gravels, sands, clays)
- Concentration of dense minerals by flowing water (placer deposits of Au, Pt. Sn, diamond)

As ores of the same metal can be formed by multiple processes, the commodity-wise genesis of common metalliferous ores is presented briefly.

- **Lead-Zinc-Silver**

  Lead and zinc deposits are formed by discharge of deep sedimentary brine onto the sea floor (termed Sedimentary Exhalative or SEDEX), or by replacement of limestone (termed as Mississippi valley type), in skarn deposits, some associated with submarine volcanoes (called Volcanogenic Massive Sulphide or VMS deposits) or in the aureoles of sub-volcanic intrusions of granite. The vast majority of SEDEX lead and zinc deposits are Proterozoic in age.

- **Copper**

  Copper occurs in association with many other metals and in varied deposit styles. Sedimentary, igneous or hydrothermal deposits of copper are common. The world's major copper deposits are hosted by the granitic porphyry. Sedimentary copper is formed by a process similar to SEDEX. Copper is often associated with gold, uranium, lead-zinc, and nickel deposits. Iron Oxide hosted Copper Gold (IOCG) deposits (Olympic Dam type) have low concentrations but very high tonnage of these metals as well as uranium and REE.

- **Gold**

  Gold deposits are formed by a very wide variety of geological processes. Deposits are classified as primary deposits, alluvial (or placer) deposits, or residual (or laterite) deposits. Often a deposit will contain a mixture of all three types of ore. Orogenic gold or lode-type gold represents one of the primary modes of gold mineralization, which contains high-grade ore in thin quartz veins. Lode gold deposits are usually hosted in basalt or in sediments known as turbidite. During metamorphism, the gold is transported up faults by hydrothermal fluid and deposited when the fluid cools too much to retain gold in solution.

  Intrusive-related gold is generally hosted in granites, porphyry or rarely, dikes. This type of gold is usually associated with copper, tin and tungsten, and rarely, molybdenum, antimony, and uranium. Intrusive-related gold deposits rely on gold existing in the fluids associated with the magma, and the inevitable discharge of these hydrothermal fluids into the wall-rocks.

  Placer deposits, sourced from pre-existing gold occurrences, are formed by alluvial processes within rivers, streams and on beaches. The Witwatersrand gold deposit of South Africa is a paleo-placers deposit, partially enriched by later hydrothermal processes.

- **Uranium**

  The uranium is leached from radioactive granites during hydrothermal activity or during circulation

[11] a sedimentary rock of hardened natural cement of calcium carbonate that binds other materials—such as gravel, sand, clay, and silt.

of groundwater and brought into solution in acidic conditions and is deposited when this acidity is neutralized. Generally this occurs in certain carbon bearing sediments, within an unconformity in sedimentary strata. Uranium is also found associated with certain igneous rocks, such as granite and porphyry. The Olympic Dam deposit in Australia is an example of this type of uranium deposit. It contains 70% of Australia's share of 40% of the known global low-cost recoverable uranium inventory.

- **Iron ores**

  Hematitic iron ores are overwhelmingly derived from ancient sediments known as Banded Iron Formation (BIFs), which are composed of iron oxide minerals deposited on the sea floor. Particular environmental conditions are needed to transport enough iron in sea water to form these deposits, such as acidic and oxygen-poor atmospheres which prevailed within the Archaean and Proterozoic Era. Supergene processes related to weathering or hydrothermal activity have resulted in the concentration of hematitic iron ore from the BIFs.

  Magnetitic iron ores are genetically related to the mafic igneous activities. Indian major magnetite deposits (Kudremukh, Bababudan) are derived from ancient sediment.

- Platinum

  Platinum and palladium are generally found in ultra-mafic rocks, which have enough sulphur to form a sulphide mineral while the magma is still liquid. This sulphide mineral gains platinum by mixing with the bulk of the magma. Alternatively, platinum occurs in association with chromite either within the chromite mineral itself or within sulphides associated with it.

- **Nickel**

  Nickel deposits are generally found in two forms, either as sulphide or laterite. Sulphide type nickel deposits are formed in essentially the same manner as platinum deposits. Nickel is a chalcophile element which prefers sulphides, so an ultra-mafic or mafic rock which has a sulphide phase in the magma may form nickel sulphides. The best nickel deposits are formed where sulphide accumulates in the base of lava tubes or volcanic flows.

  Some sub-volcanic sills in the Thompson Belt of Canada host nickel sulphide deposits formed by deposition of sulphides near the feeder vent. Sulphide was accumulated near the vent due to the loss of magma velocity at the vent interface. The massive Voisey's Bay nickel deposit is considered to have formed via a similar process. Significant nickel sulphide accumulations are seen in the conduits and lava tubes of continental basalt and in the locales of thermal erosion in the underlying sediments in Noril'sk-Talnakh deposits, Siberia. The process of forming lateritic nickel deposits is essentially similar to the formation of lateritic gold deposits, except that ultramafic or mafic rocks are required.

- **Tin, tungsten, and molybdenum**

  These three metals generally form in a certain type of granite, via a similar mechanism to intrusive-related gold and copper. They are considered together because the process of forming these deposits is essentially the same. Skarn type mineralization related to these granites is a very important type of tin, tungsten, and molybdenum deposit. Skarn deposits form by reaction of mineralized fluids from the granite reacting with wall rocks such as limestone. Skarn mineralization is also important in lead, zinc, copper, gold, and occasionally uranium mineralization. Molybdenum is a common constituent of porphyry copper deposits and also occurs in association with hydrothermal sulphide.

- **Rare earth elements, niobium, tantalum, lithium**

  The overwhelming majority of rare earth elements, tantalum, and lithium are found within pegmatite. Ore genesis theories for these ores are wide and varied, but most involve metamorphism and igneous activity. Lithium is present as spodumene[12] or lepidolite[13] within pegmatite. Carbonatite[14] intrusions are important source of these elements.

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[11] Spodumene is a pyroxene mineral consisting of lithium aluminium inosilicate, $LiAl(SiO_3)_2$

[12] Lepidolite is a member of the mica group of minerals with formula $K(Li, Al, Rb)_2(Al, Si)_4O_{10}(F, OH)_2$.

[13] Carbonatite: a type of intrusive or extrusive igneous rock defined by mineralogic composition consisting of greater than 50% carbonate minerals

Looking for Deep Located[14] Mineralization in India

With the exhaustion or fast decline of mineral deposits at shallow depths of the earth's surface, it has become imperative the world over to look at deeper levels of the earth's surface for mineral resources for meeting the ever growing need of mankind.

Given the intrinsic uncertainty and risk, exploration of deep-seated mineral deposits is essentially a sequential procedure, based on sound technical principles which are constantly refined with greater knowledge generated through successful exploration. The successive steps of the sequential exploration are based on a data-driven probabilistic approach. Generating better and better data through adoption of constantly improving technologies is key to increasing the probability of success.

Stages of search

The exploration of deep seated mineral resources, without having much apparent surface shows, is not a venture in isolation but requires a clear understanding and of the causative processes and factors which could lead to possible mineral localization. Therefore, the endeavour:

- draws heavily on the fundamentals of geosciences, specially the aspects of crustal evolution and metallogeny.
- demands rigorous work in the field and the laboratory with the application of latest techniques and technology
- depends on efficient data integration into multilayered GIS and preparation of stage-wise interpreted 3-D models (mineral belt model, deposit model, ore body model); and
- requires sizeable investment, over prolonged periods, with appreciable risk of non-return on the investment.

The search of deep seated deposits may be driven by:

- Concept-based mineral belt modelling (especially in virgin or greenfield areas)drawing on geological principles; or
- Data-based expectation (on the basis of shallower level deposits existing in a brownfield area) and geoscientific possibility of similar metallization at depth.

Guidelines for the search

Selection of potential target areas for exploration is based on specific geological parameters, which are useful in developing a prototype conceptual genetic model. For example, the theory of Plate Tectonics has dramatically improved our understanding of basic endogenic and exogenic processes or systems responsible for mineralization and possible locations of such systems in the Earth's crust. These processes can now be better modelled through application of experimental and theoretical geoscientific knowledge (e.g., geochemistry, fluid inclusion, geo-thermometry and geo-barometry, stable isotope systematics, hydrothermal alteration studies, robust geo-chronological determinations, radiogenic tracers, computer-based simulations, and remote sensing) to build working hypotheses, which can be put to ground test for locating concealed deposits. Additional or better quality data aligned to the hypothesis can validate (or modify or invalidate) the hypothesis, increasing the probability of mineralization as well as of locating it.

Characteristics of mineral deposits

The genesis of mineral deposits can be varied:

- Sedimentary processes of mineralization include direct precipitation of ore material from sea water and/or their subsequent concentration.
- Magmatic processes, plutonic or volcanic, involve fractional crystallization or melts of differing composition.

[14] The Paper uses the terms "deep seated", "deep located", and "concealed" deposits in a nearly interchangeable way though there are slight differences.

*[15] **Exogenic processes** are those driven by **exogenic** forces that primarily derive their energy from solar radiation. For instance, soil erosion is caused by the force of wind acting on bare ground. **Endogenic processes** are those that get their energy from **endogenic** forces originating deep within the Earth.*

- Hydrothermal processes caused by movement of hydrothermal solutions within the crust, often as a consequence of magmatic intrusion or tectonic upheavals. Sources of hydrothermal solutions include seawater and metamorphic fluids created during metamorphism.

A comprehensive understanding of the possible ore genetic criteria in a particular geological domain with the signature of crustal processes (sedimentary, magmatic, hydrothermal, metamorphic or their combination) is the primary task. Prognosis of the factors which could be responsible for ore concentration through the analysis of theoretical possibilities and assessment of indicators would be the next step in concept building.

Brownfield and Greenfield exploration

Geologically favourable areas for mineral potential depend on the particular mineral commodity or group of commodities under search. The region favourable for gold mineralization may not be coincident with those for lead-zinc or bauxite mineralization. There are two broad categories of terrains, viz., Brownfield and Greenfield.

Exploration is termed Greenfield if either no exploration has been conducted for the minerals of interest or previous exploration has not increased the probability of mineral occurrence; and Brownfield if some previous exploration has been conducted and there are known ore deposits. Greenfield exploration is highly conceptual, relying on the predictive power of ore genetic models to search for mineralization in unexplored ground. Greenfield exploration has a lower success rate, because the actual geology may be poorly understood at the start of the venture, or the concept on the basis of which the venture is being undertaken may not be applicable to the exact situation of the target area. Brownfield exploration is less risky, as the geology is better understood and exploration methodology is well known; however, the risk can still be significant.

A genetic model attempts to describe the physical and chemical processes that led to the formation of an ore deposit and its related empirical features. In Brownfield areas, exploration may rely on genetic ideas. The careful use of models based on a full empirical database and well constrained genetic theory, allows the geologist to place some degree of confidence on the chance that these targets will contain economic mineralization. In case of Greenfield search, the conceptual approach is to be built up on the basis of geological understanding of the depositional and tectono-magmatic set-up of the region, its age and relation to overall crustal evolutionary trend and metallogeny of that era. Synthesis and critical appraisal of the available regional geological geochemical, geophysical, remote-sensed data and assessment of indicative evidences of mineralization, if any, aided by literature scanning and pragmatic evaluation of global case histories of mineral discoveries in similar geologic environment would be equally important. Petrological characterization of the rocks (specially the magmatic units), picking-up of evidences of hydrothermal activities, detailing of metamorphic-metasomatic transformations, fluid inclusion and isotope studies, etc., may provide important clues in Greenfield investigations.

Area selection

In India, the greatest operational advantage is the availability of geological maps for the entire country on 1:250,000 and 1:50,000 scales. Regional ground gravity-magnetic (GM) data, high altitude aeromagnetic data and various interpretative compilations are available for large areas of peninsular India. Besides, airborne multisensor (magnetic+ electromagnetic (EM) + radiometric) geophysical survey data are available for most of the known mineral belts. Aided to these are the satellite imageries. All these datasets, when collected, collated, and synthesized, will provide the avenues for the first step towards the identification of geologically favourable domains, in both Brownfield and Greenfield.

After identifying favourable geological milieu for mineral search (with specific mineral commodities in view) in the Brownfield or Greenfield territories, which may run into thousands of square kilometres, the next task would be to select and prioritize target areas where more intensive exploration need to be planned. The exploration methods generally adopted at this stage are:

- Integrated study of remote sensed data, high altitude airborne survey data, and regional ground geophysical data in conjunction with regional geological maps

- Low-altitude multi-sensor airborne surveys with software support for data synthesis and interpretation aimed at anomaly location
- Regional grassroots geochemical surveys (stream sediments, rock, soil, gas)
- Ground geophysical surveys in selected areas
- Limited experimental test drilling; and
- Field and laboratory studies aimed at mineral prognosis.

At this stage, computer-based multivariate statistical analyses may establish characteristic inter-relationships of various parameters and lead to mineral belt modelling. The application of all the reconnaissance tools and data interpretation would need sound understanding of the overall geological and metallogenic environment. Ages of metamorphism, deformation, and intrusive events need to be established by robust geochronology in the area under study. There needs to be more emphasis on accurate dating of mineral deposits to define the critical age peaks of major mineral types. The geophysical and geochemical methods recommended for this stage of exploration and their basic principles are explained below.

Use of Airborne Geophysical Surveys

Where the surficial layers are of relatively recent origin and the favourable geological milieu occurs at some depth, the search for the "concealed" mineralization requires the application of geophysical techniques which can enable an understanding of the deeper layers. Fast-paced regional scanning by geophysical applications is needed at this stage for picking up responses of deep seated mineralization.

A choice must sometimes be made between helicopter and fixed-wing aircraft for an airborne electromagnetic or radiometric survey. Helicopters have an advantage in being able to maintain a more constant ground clearance above rugged terrain. Also, helicopters have a slow-flying capability, which allows for greater accuracy and they can land for a ground check in critical areas. Helicopter geophysical surveys can therefore be used in detailed work as well as in reconnaissance.

Among the airborne survey systems most popular are the aero-magnetic, aero-electromagnetic (AEM) and aero-Radiometric systems. Airborne Gravity surveys have also gained much utility as a fast reconnaissance tool. There is a vast choice of patented instruments with add-on data processors and interpretative software available with the multitude of survey agencies. A right choice of airborne systems would depend on the overall appreciation of the nature and disposition of the targeted geological entity, its surface and deeper environment, besides the physiography.

Use of Geochemical Survey data

One application of geochemistry in mineral search is to pick up the trace of ore building elements in the rocks and follow these to the locus of concentration at depth, called the litho-geochemical survey (bed-rock geochemistry). The other, far more widely used, is to pick up the products of partial disintegration (in soil, stream sediments, soil gas, etc.) of an ore body and trace these back to the source, called the pedo-geochemical and stream-sediment surveys. While looking for primary anomalies in bed rock is more appropriate after target / prospect selection, regional soil, soil gas or stream-sediment surveys aimed at locating secondary dispersion anomaly are essential at the reconnaissance stage. For the mineral exploration agencies, the development of reliable methods for the detection of ore deposits covered by overburden is critical to their risk reduction and future success. For the exploration methods to be reliable, an understanding of the dispersion processes is required.

The emergence of hydrogeochemistry and biogeochemistry as important exploration techniques in concealed and leached terrains needs serious attention. Application of hydrogeochemistry is well known and in vogue in the sequential stages of exploration.

Limited ground geophysical surveys and experimental test drilling in selected areas: ground truthing

Ground geophysical surveys may become necessary if the aero-geophysical data are either less specific or not matching with geological-geochemical data-sets. Very Low Frequency Electromagnetic (VLF) survey, which is a rapid and cheap method, may be useful at this stage. Controlled Source Audio magnetic-tellurics (CSAMT) is also a low-cost geophysical technique that provides deep geologic information based on lateral and vertical resistivity contrasts. In any case, ground truthing of the aero-geophysical surveys needs to be done. This may include limited test drilling and sample analysis for discerning the stratigraphy or verifying mineralization. Drill core studies (petrology, mineralogy, analytical, etc.) at this stage may generate vital information, helping in the ultimate zooming into the target.

Potential for Locating New Mineral Resources in India

Himalayas

Both from the point of view of plate tectonic status of this continent–continent collision zone and its comparison with the Alpine belt, the Himalaya deserves a thorough scanning for possible but varied metallogeny ranging from sedimentary-digenetic types in the frontal belt, SEDEX type and hydrothermal deposits in the Lesser Himalaya, Tertiary granitic pluton related metallization in the Central crystalline zone, bedded deposits in the Tethyan sediments, ophiolite related metallization along the Indus–Tsangpo suture zone and porphyry type deposits in the Trans-Himalayan region.

Bundelkhand granite-gneiss complex

It is now known, after discovery of the Pearl Lake deposit in Canada that porphyry copper deposits were formed during early Precambrian time. Precambrian porphyry deposits have been discovered in Australia, Finland, Canada, China, Sweden, and many other countries. The Malanjkhand Cu-deposit in MP, India is now recognized as one of the largest of this type, much later than its discovery. The vast Bundelkhand granitoid complex could therefore host porphyry sulphide or shear controlled hydrothermal mineralization. Concept oriented deeper probe should be a priority task in this region.

Deccan Trap covered region

About half a million square kilometres of west-central part of peninsular India is covered by the largely Mesozoic continental flood basalts known as Deccan Traps. The Deccan Trap covered terrain remains almost entirely unexplored. The oil companies have conducted extensive geophysical investigations to locate favourable structures in Mesozoic sediments underlying the trap (and also some drilling), but no effort was directed towards prognostication of metalliferous deposits. Other than the possibility of locating mineralized tracts in the Precambrian basement rocks, there are two broad possibilities of metallization within the Deccan volcanics, i.e., magmatic sulphide; and hydrothermal mineralization.

Other terrains that warrant a closer look

The following Brownfield areas among others may deserve a relook in search of deep-seated deposits:

- The Dharwar craton may be re-examined for locating greenstone related orogenic gold at deeper levels of the numerous schist belts, many of which have sub-economic gold occurrences at the surface. The Kolar Gold Field cannot possibly be the only place where economic gold values continue up to great depths. The Wynad-Nilambur Gold Field in Kerala also merits a concerted effort to locate deep seated gold mineralization.
- India is the only country in the world which in spite of having a vast Precambrian shield area does not have any nickel mining activity. No primary nickel sulphide deposit has so far been located. It may need a sustained campaign to look for both primary nickel and PGE in favourable domains.
- The Southern Granulite Terrain (SGT) should not be neglected for mineral search, as it is established now that a mineral deposit does not get dissipated by high grade metamorphism. Broken Hill Pb-Zn deposit in Australia; Renco gold deposit in felsic granulites of the Limpopo belt, Zimbabwe; gold in the high grade terrain of North China craton are some prominent examples. Though the Zn-Cu-Pb deposit in SGT at Mamandur, Tamil Nadu is small, it would certainly provide a clue to the suggested line of action. Gold mineralization in Attapadi valley, Kerala, also presents a case in favour of searching the granulite terrain.
- Serious research is needed to identify IOCG type metallogeny in India, which may provide vast opportunities for locating new deposits at depth. The copper-gold-uranium belts of northern Rajasthan, Singhbhum, and some areas in Chhattisgarh might merit a close scrutiny in this respect. Presence of mafic volcanics, high content of magnetite, profuse albitization (soda influx), hydrothermal hematitic breccia, etc., may be considered together as a starting point.

- As hematitic iron ore is no longer considered as the sole product of supergene process, it would be prudent to explore at depths beyond conventional limits to locate hydrothermally enriched ore horizons. Ample evidence have been gathered, from many Indian deposits, in favour of the existence of pre-deformation epithermal concentration of rich iron ore below the zone of supergene concentration.
- In the peninsular India, there are many crustal domains where concerted efforts should be directed for the location of Precambrian porphyry copper type deposits. The Malanjkhand Granite being equivalent in age to the much larger expanse of the Dongargarh Granite, the latter may form the immediate target for the search.

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The Energy and Resources Institute (TERI)
Darbari Seth Block, IHC Complex, Lodhi Road,
New Delhi- 110003

Tel: 71102100 or 24682100
Fax: 24682144 or 24682145
Web: www.teriin.org
E-mail: pmc@teri.res.in