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Article

India's Need for Strategic Minerals

Ajey Lele

Abstract

Assured supply of critical and strategic minerals is vital for the defence and security of India as well as its transition to a more advanced low fossil fuel based industrial economy. The space industry, electronics, information technology and communications, the energy sector, electric batteries, the nuclear industry among others are all significantly dependent on various critical minerals and rare earths. India is a mineral-rich country and availability of most minerals should not be an issue. However, the real challenge is that of excavation, processing, research, and investments. The strategic mineral sector in particular and the mining sector in general is expected to face difficulties in meeting the growing demand in vital sectors in the coming years. Import dependency for strategic minerals is one of the most obvious challenges. Besides expanding prospecting and improved processing, India also needs to significantly increase the research focus in all relevant areas of technology and to undertake research on recycling of minerals and finding the correct substitutes. The role of the private sector in mining and the minerals sector also needs to increase.

Strategic materials are increasingly important to the development of a nation-state in general and its security in particular. It is important to appreciate that states are wary about making specific information public, with regard to their needs and plans for strategic minerals for obvious reasons. This limits empirical assessment about the needs, capabilities and limitations of a nation-state in this arena. This paper undertakes a broad-based analysis of India's need for strategic minerals since no demand-supply-deficiency assessment has been carried out, so for.

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What are Strategic Minerals?

Mineralogy is perhaps the oldest branch of material sciences, and is also considered as the oldest branch of geology. For several centuries, mineralogy dealt with materials that appear in nature as minerals, and it still continues to provide motivation to material chemists in the synthesis of new materials.[1] There are various definitions of the term mineral. Any mineral is a naturally-occurring inorganic substance (homogeneous solid) with a definite and predictable chemical composition and physical properties. Different minerals could be based on the nature and the arrangements of the atoms made inside them.[2] Minerals, in general, are obtained through mining and processed further, based on requirement. Organic substances like coal, natural gas, and petroleum could also be categorised as minerals, though many discussions (including this paper) on this subject do not treat them as minerals.

Research on minerals has been ongoing for a number of years. Prof James Dwight Dana from Yale University is widely recognised for his work on mineral classifications. He presented the first organizational structure for minerals during 1837. The first five editions of 'A System of Mineralogy', were published through 1837, 1844, 1850, 1854, and 1868, and were authored or revised by Prof Dana. Every new edition saw an enormous increase in knowledge due to extensive research undertaken in this field. The first edition described all 352 minerals known at that time. At present, the world is in the know of about 4000 types. However, even today the basic classification presented by Dana continuous to be valid. The Dana system divides minerals into eight basic classes, namely: native elements, silicates, oxides, sulfides, sulfates, halides, carbonates, phosphates, and mineraloids.[3] Most of the new minerals found during 20th and 21st century could be fixed into these basic classes.

Amongst different minerals some are special. They attain special status owing to short-supply, controls, cost factor and utility for strategic industries. Also, there are mineral-rich countries as well as mineral-deficient countries. However, mineral excavation requires significant financial investments and technology proficiency. Hence, there are some states which are mineral-rich but are unable to mine them. Relevance of a particular mineral could vary from state to state based on needs and availability. There are wide-ranging usages of various mineral resources. Essentially, they are the lifeline for industrial setups, particularly for the construction industry and other associated industries. Minerals have relevance for the communications and electronics industry too. Their importance for the defence industry and other strategic industries like energy, nuclear and space make their significance very distinctive.

Generally, Strategic Minerals (also known as Critical Minerals) is a broad category that identifies various minerals and elements; the bulk of which are minor metals. Geography and availability of domestic supply normally defines the "critical" nature of minerals for any particular region or a country.[4] A nuanced distinction between the words strategic and critical implies that critical materials have relevance for the overall interests of the state, while strategic minerals are essentially those minerals which have relevance for the defence/strategic architecture of the state.

Keeping military need as a key focus, strategic minerals (also sometimes termed as strategic materials) generally could be defined as those:[5]

- that are needed to meet the military, industrial and essential civilian requirements of a state during a national emergency;
- that are not found or produced in sufficient quantities to meet such needs of the state

From the list of around 4000 minerals, it is challenging to exactly isolate strategic minerals. Also, as mentioned above a mineral which is strategic for one state may not be strategic for another. Still, in literature there are references made to some minerals which could be broadly considered as strategic minerals universally. Some of these minerals are mentioned below. No specific methodology has been followed for this identification, which is broadly based on observation and factoring the mineral requirements of the strategic industries.

Vital Strategic Minerals include Antimony, Molybdenum, Borates, Nickel, Chromium, Cobalt, Silver, Copper, Titanium, Diamond, Tungsten, Germanium, Vanadium, Lithium, Zinc and Rare earths.[6]

Minerals and Mining in India

The geology of India is diverse. Different parts of India contain rocks belonging to different geologic periods and there are varied geological structures. Variety of mineral deposits are found in the Indian subcontinent. In addition, India is a geographically unique state. It has range of geographical features from mountain ranges, snow-capped mountainous ridges, thick vegetated forests, rain forests and deserts, and a long coastline. The difficult geography at times makes it tough to access some of the minerals rich areas.

Owing to the exceptional stability of the Indian peninsula, its rocks have been comparatively less mineralised. It is only in the very oldest rock structures, metallic ores occur in valuable quantities. But their discovery is often difficult, as they are buried underneath the protracted accumulation of weather material.[i] Sir T. H. Holland, a former Director of the Geological Survey of India during the colonial period, published in 1908 a very detailed sketch of the mineral resources of India providing detailed description about various available minerals. In this publication he presented a categorisation of mineral products in India. The categories identified are: Carbon and its Compounds, Metalliferous Minerals and Metals, Minerals used in various Industries and Gem-stones. The study stated that the mineral industry and mining activities in India went through many ups and downs from the late 1800s to early 1900s.[7] Around this period, the key minerals in use were iron, lead, copper, tin, zinc and antimony.

Given the importance of minerals in the overall growth of the country, almost immediately after independence, the Indian Bureau of Mines (IBM)[8] was established (during 1948) as a multi-disciplinary government organisation under the Department of Mines, Ministry of Mines. The primary mission of the Indian Bureau of Mines is to promote the scientific development of mineral resources in the country (both onshore and offshore) other than coal, petroleum & natural gas, atomic minerals and minor minerals.

Broadly, there are two categories of minerals: Major minerals and Minor minerals. The Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act 1957) defines "Minor minerals" as the minerals like building stones, gravel, ordinary clay, ordinary sand other than sand used for prescribed purposes, and any other mineral which the Central Government may, by notification in the Official Gazette, declare to be a minor mineral. Interestingly, there is no definition of major mineral in this act. The first schedule appended in MMDR Act 1957 has three mineral categories under the head 'Specific Minerals'. These categories include Hydrocarbon Energy Minerals, Atomic Minerals and Metallic and Non-Metallic Minerals. Normally, the category of Metallic and Non-Metallic Minerals gets referred to as major minerals.[9] Asbestos, Bauxite, Chrome ore, Copper ore, Gold, Iron ore, Lead, Manganese ore, precious Stones and Zinc belong to this category.

Though minerals production in India increased considerably during 1960s, it was also realised that India's mineral deposits were less than the USA, erstwhile USSR, Canada and South Africa. Mineral exploration is a continuous process and demand significant technical expertise and financial investments. Owing to these reasons, during the initial years after Independence, it was difficult for India to explore its vast area of

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i. A review of Sir T. H. Holland, *Sketch of the Mineral Resources of India,* London and Calcutta, 1908, published in Nature April 8, 1909, No 2058, Vol 80, p. 163

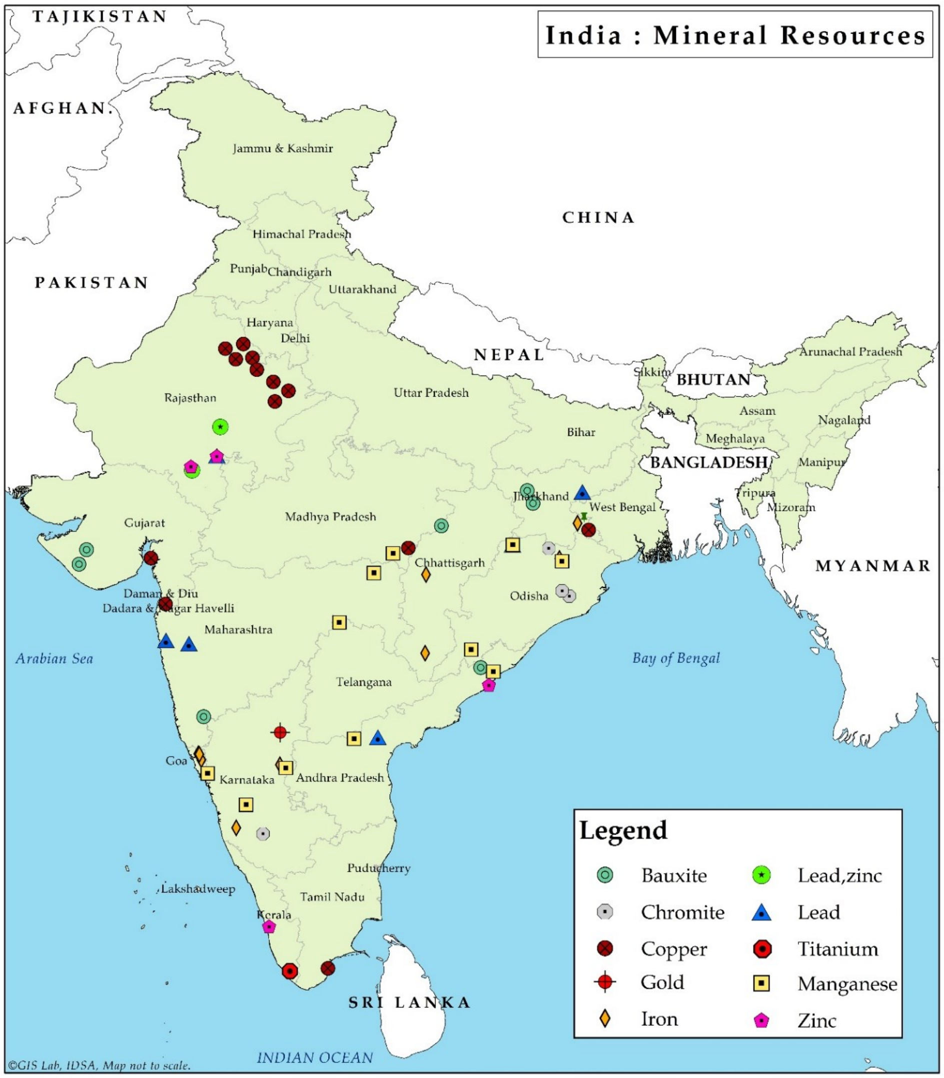
mineral deposits. In addition, owing to technology limitations then, it was not possible to undertake precise geological mapping.[10]

India is acknowledged as a nation well-endowed in natural mineral resources. It ranks 4th amongst the mineral producer countries, behind China, United States and Russia, on the basis of volume of production, as per the Report on Mineral Production by International Organizing Committee for the World Mining Congress.[11] Various mineral deposits are found in India. The country produces around 87 to 89 minerals, including 4 fuel minerals, 10 metallic minerals, 49 non-metallic minerals, 3 atomic minerals and 22 minor minerals (including building and other materials).[12] India's domestic mining sector contributes about 10% -11% to the industrial sector and about 2.2% - 2.5% to the economy's GDP[13] --which is one of the lowest vis-à-vis some of the larger emerging economies such as China (20 per cent), Australia (8 per cent) and Russia (14.7 per cent).[14] This contribution has not shown much of a variation post-2011, and during some years it has actually reduced to approximately around two per cent to the GDP.

The major portion of mining in India, almost 80% is that of coal and the rest 20% constitutes of very many metals and raw materials such as gold, copper, iron, lead, bauxite, zinc and uranium. India has a well-oiled network which undertake various tasks associated with mining. India tops the world in respect to mica and mica splitting. The country ranks third in the production of coal, barytes and chromite. India stands 4th in iron ore production and 6th in bauxite and manganese. India is also among the top ten countries in respect of aluminium production and stands at number ten.[15] India's mining industry constitutes a large number of small operational mines. The average number of mines which reports production [excluding minor minerals, petroleum (crude), natural gas and atomic minerals] in India are about 2000.

As per the Annual Report 2017-18 of Ministry of Mines[16] there has been around 8 to 12% increase in the production of minerals every year (for financial year 2018 it was 13%). The number of small operational mines in the country, excluding atomic, fuel and minor minerals, was 1,531 in 2017-18. Around 200 each of these mines are in Tamil Nadu, Madhya Pradesh and Gujarat. However, Rajasthan is in the leading position in terms of estimated value of mineral production in the country. It had a 20.26 % share in the national output, followed by Odisha with 17.77%.

The following diagram broadly depicts India's important mineral resources:



India's geological features are known to be broadly similar to that of Western Australia, particularly in relation to iron ore, bauxite, coal, diamond and heavy minerals. India has identified 5.71 lakh sq. km as the obvious geological potential (OGP) area, but, only 10% of it has been explored and 1.5% is being mined. India also has potential to mine minor minerals. It is estimated that their share in the value of production is about 26%.[17]

India's Strategic Minerals

The initial effort to define strategic materials/minerals/resources was made by the US Army and Navy Munitions Board following World War I. Two classifications were identified: strategic minerals and critical minerals. Strategic minerals were distinguished by their essentiality to the national defence, their high degree of salience in wartime and the need for strict conservation and control over distribution. While, Critical minerals were considered less essential and more available domestically, requiring some degree of conservation.[18]

In the Indian context, one of the early references to the issue of strategic minerals is found in an article published in the Defence Science Journal in 1952.[19] It was argued that strategic minerals include, besides materials for combat munitions, all mineral raw materials required for industry. The paper mentions that India does have ample and well distributed domestic mineral resources. In respect of strategic minerals as well India is mostly self-sufficient, it said. It identified the minerals which are vital for war and also strategic minerals which are deficient in the Indian context. However, no rationale for such identification was provided. Ten minerals, namely Sulphur, Lead, Petroleum, Zinc, Mercury, Platinum, Nickel, Graphite, 'Tin and Ferro-tungsten were identified as strategic minerals which are available in short supply in India.

Broadly, any military industrial complex is connected with the development of transport, intelligence gathering and weapon platforms (aircrafts, ships, submarines, tanks, UAVs, etc.). This industry also covers production of weapons and ammunition (guns, bullets, bombs, missile etc), ground infrastructure and support equipment (radars, sonars, staircases, batteries, tents, functional food, etc). Essentially, the nature of threat dictates the possible type of warfare a state is likely to face. The warfighting doctrines of the state identify the broad nature of equipment needed by the armed forces. India need to remain prepared to fight asymmetric, conventional and nuclear conflicts. Hence, almost every from of defence industry -- from ground systems to aerospace to missile building to ship and submarine building industry --is important for India. Obviously, minerals required for all these industrial sectors are critical and hence, could be considered as strategic.

It is important to appreciate that defence industry constitutes only a portion of the strategic industry. There is a very thin-line that differentiates (in some sectors) between what is a military industry and what is a civilian industry. Space industry, Electronics industry, Information Technology and Communications industry products, all have utility in diverse sectors, including the defence sector. In addition, energy industry, including the nuclear sector, is significantly dependent on various critical minerals. Possibly, that is why India's overall focus during the first five to six post-independence decades was to establish the mineral sector as a whole without making any differentiation between conventional and strategic industry.

At present, however, Indian policy makers are keen to identify the strategic minerals exclusively. An effort in that direction is visible in a report published by the Planning Commission in 2011. This report specifically identifies strategic minerals and metals. They include Tin, Cobalt, Lithium, Germanium, Gallium, Indium, Niobium, Beryllium, Tantalum, Tungsten, Bismuth and Selenium and Rare Earths.[20] In the following paragraphs[21] some basic information is provided about these minerals.

Beryllium is a steel-grey, hard and light metal. It is lighter and almost six times stronger than the steel. It is non-magnetic and has excellent thermal conductivity with very high melting point. Its exceptional ability to form alloys with many important materials has increased its importance for strategic equipment development and production industry. It has been declared as a critical and strategic mineral by many countries, including the US, EU and China. It has wide applications in electronics, aerospace, transport systems and medical instrumentation.

Bismuth is a hard, brittle, lustrous, and coarsely crystalline material. In ancient times, this metal was often confused with lead and tin, which share some of its physical properties. It has the lowest thermal conductivity among all metals, and it is the most diamagnetic of all metals. It is useful as an element type-metal alloy and also used of for castings purposes due to its unique property to expand after solidification. It is mostly used as an ingredient in pharmaceutical products and semiconductor devices. It is used as a carrier for two uranium isotopes in nuclear reactors, in fire systems and mobile refrigerators, and for cooling computer processors.

Cobalt is a brittle, hard, silver-grey transition metal found in association with copper, nickel and arsenic ores. Its alloys possess useful properties such as high temperature melting point (1493°C), ferromagnetic, multivalent, etc. It has the ability to retain its strength and properties even at high temperatures. Super-alloys made of cobalt have improved strength and wear and corrosion-resistant characteristics at elevated temperatures. This metal has diverse industrial and military applications. It has a wide range of applications in renewable energy and reusable energy storage systems, manufacturing of turbines and compressors, in jet engines, radar systems for stealth technology, and nuclear industries.

Gallium is a soft, silvery metallic element and was first used in high-temperature thermometers. It melts at a low temperature (29.75°C) and has an unusually high boiling point (~2,204°C). Presently, Gallium has wide applications from manufacturing of semiconductors, data-centric networks to smartphones.

Germanium is a lustrous, hard, greyish-white metalloid. It is unaffected by acids and alkalis, except nitric acid. The properties of germanium is most closely associated with silicon. It easily forms compounds with arsenic, gallium and some other metals. It is used in transistors and in integrated circuits. It also has utility in the production of infrared spectroscopes and infrared detectors

Indium is a rare, soft, malleable and easily fusible heavy metal. It remains soft at low temperatures and is most suitable for solders. Indium has very specific usage, but the most important current use of Indium is in flat panel displays, Plasma Display Panels (PDPs), Liquid Crystal Displays (LCDs), and Organic Light Emitting Diode (OLED) screens, which account for upwards of 80 per cent of all demand. Also, because of its high sensitivity to temperature, Indium is used in nuclear industry to make control rods for batteries in atomic reactors. It is also used as a glass coating for aircraft windshields and in the semiconductor industry for making germanium transistors, thermistors, rectifiers and photocells.

Tantalum, is a hard, blue-grey, lustrous transition metal. It is corrosion resistant and is closely related to niobium in terms of physical and chemical properties, often even considered identical. It is used in the manufacturing of cutting tools and electronic circuits in protection systems for steel structures such as bridges and water tanks.

Tin, one of the most commonly known and used minerals. It is easy to recycle, has a low melting point, is malleable, is resistant to corrosion and fatigue and has the ability to alloy with other metals. Tin is one of the oldest metals known to mankind and is used in combination with copper to make bronze. Tin can be used in both in industry and also in the form of chemical compounds. Its usage lies in electrical components such as capacitor electrodes, fuse-wires and major usage in soldering wires, which make it a vital mineral in the electronic industry.

Tungsten, also called "wolfram", has the highest melting point (3,422±15°C) and boiling point (5,700°C) of all metals. The coefficient of thermal expansion of tungsten is lowest in all metals; hence, it is widely used in the filament of bulb and high-speed cutting tools with carbide. Presence of carbon and oxygen gives tungsten considerable hardness and brittleness. Tungsten gets used in making special and alloy steels and is widely used in cutting and wear-resistant materials. Its utility for electrical and electronic systems/ equipment is well known. It is also used in armour plate and armour-piercing ordnance.

Niobium, formerly known as columbium is a soft, grey, crystalline, ductile transition metal. This mineral is used with iron and other elements in stainless steel alloys and also in alloys with a variety of nonferrous metals, like zirconium. The various alloys made by using this mineral are strong and are often used in pipeline construction. It has also utility for aerospace industry and gets used in manufacturing of the jet engines and heat resistant equipment.

Selenium, is a chemical element with properties that are intermediate between the elements sulphur and tellurium, and also has similarities with arsenic. It rarely occurs in its elemental state or as pure ore compounds in the Earth's crust. It is found in metal sulphide ores and is produced as a by-product in the refining of these ores, most often during production. The chief commercial uses of selenium today are in glassmaking and pigments. Gets used in metal alloys like lead plates used in storage batteries and in rectifiers to convert AC current into DC current. Selenium is used to improve the abrasion resistance in vulcanized rubbers.

The Rare Earth Elements/Minerals (REEs/REMs) do get deliberated upon as a distinct category away from strategic minerals owing to their explicit qualities and relevance for defence industry. They are a set of 17 elements at the bottom of the periodic table used in a variety of renewable energy and defence applications, including precision guided munitions, wind turbines, unmanned aerial vehicles, hybrid vehicles and tactical wheeled vehicles.[22] REE exhibit a range of special (some unique) properties which are used in many modern and "green" technologies. The International Union of Pure and Applied Chemistry defines the Rare Earth Elements as the 15 lanthanides together with yttrium and scandium.[23] REEs typically fall into the categories like:[24] Light Rare Earth Elements (LREEs) and Heavy Rare Earth Elements (HREEs), with varying levels of uses and demand. REE mineral deposits are usually rich in either LREEs or HREEs, but rarely contain both in significant quantities.

- Heavy Rare Earths are Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb), Lutetium (Lu) and Yttrium (Y)
- Light Rare Earths are Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd) and Samarium (Sm)

Apart from the 2011 study of the Planning Commission, another study undertaken during 2016 for the Department of Science and Technology (DST) identifies shortage of 13 critical raw materials needed to feed India's growing economy over the next 15 years. The report mentions that India's plans to expand its aerospace industry could be threatened by a domestic shortage of vital raw materials. It highlights India's heavy dependence on China. The report argues that the materials in short supply are vital, if India wants to make a transition to a high-tech manufacturing economy. These critical raw materials include rhenium, germanium and rare earths, limestone and also graphite. Also, since all major green technologies depend heavily on rare earths India needs to device a policy for rare earths production. Luckily, India has some deposits of mainly lighter rare earth elements, but it needs to import heavier rare earths. India is also completely dependent on other countries for rhenium, used to produce super-alloys for the aerospace industries, and also germanium, used in electronics. If India wants to elevate its manufacturing capabilities by 2030 in the areas such as aerospace, electronics, defence and nuclear energy, then it must clearly manage its raw material imports and domestic production.[25]

India's plans to expand its aerospace industry could be threatened by a domestic shortage of vital raw materials.

Policy Structures: Mining/Mineral Sector in India

Indian Bureau of Mines regularly publishes the Indian Minerals Yearbook providing all requisite details about the global scenario, India's production cycle, exports, imports and details about the substitutes. At a policy level certain important guiding documents are available which get routinely updated. The Mines and Minerals (Regulation and Development) Act, 1957 was enacted to provide for the regulation of mines and development of minerals. This act has been amended more or less once every decade (as per the requirements to bring in changes in the policy on mineral development) Two of the key regulations in the sector are:

1. Mines and Minerals (Development and Regulation) Amendment Act, 2015

The MMDR Amendment Act, 2015 specifies that the mineral concessions for major minerals will be granted through auction or competitive bidding. It also states that the mines will be granted for a fixed tenure and will be made easily transferable; strict penalty provisions will be introduced to stop illegal mining; and a National Mineral Exploration Trust (NMET) will be established to conduct detailed exploration on a regional basis.

2. Atomic Minerals Concession Rules, 2016

The Ministry of Mines, Power, Coal, and New & Renewable Energy have decided that the State Governments will now grant mineral concessions, where atomic mines are less than the prescribed threshold values, to the private sector by auction or competitive bidding.

The first National Mineral Policy was enunciated by the Government in 1993 for liberalisation of the mining sector. The National Mineral Policy, 1993 aimed at encouraging the flow of private investment and introduction of state-of-the-art technology in exploration and mining. This policy was replaced with a new National Mineral Policy during 2008. In 2018 a new draft policy has been circulated to cater for the present day requirements. Currently, in the mining sector, there are various government supported autonomous agencies[ii] and private industries making significant contributions.

The 2018 draft policy document mentions that the mineral exploration would be incentivised to attract private investments. However, the policy still lacks clarity on the actual fiscal incentives for potential investors. Since, mineral exploration is a risky business, no big investor is likely to make investments without clear assurances in regards to finances and technological assistance. Also, the policy has no provisions for transfers of mineral concessions as is the normal practice in other mineral rich nations.[26] The mining sector also suffers from several shortcomings in the licensing regime such as the separation of auction for prospecting licenses from provision of mining licenses that need to be overcome.[27]

A new report called the 'Critical Non-Fuel Mineral Resources for India's Manufacturing Sector: A Vision for 2030'[28] offers a first-of-its-kind framework for India to identify the 12 critical minerals (including beryllium, germanium, rare earths (heavy and light), rhenium, tantalum, etc.) that can play an important role in the Make in India programme, and assesses the impact of these critical minerals on the manufacturing sector. It also weighs the economic importance of these minerals and associated supply risks.

Challenges for India's Mining/Mineral Sector

Broadly, the strategic mineral sector is expected to face similar difficulties as that of the entire mining sector. Import dependency is one of the most obvious challenges. Normally, such dependence materialises either because the minerals are physically not available within the physical geography of the country or the excavation of the minerals is not possible/feasible. It is important to note that on occasions, in spite of having minerals available in the backyard, the import of mineral becomes more cost-effective than creating an industry-structure for its extraction within the country. Also, India faces various challenges such as the high cost of acquiring land and on occasion local resistance for land acquisition. In addition, there are major challenges such as Naxalism. There apparently is an interrelationship between the Naxalite conflict and India's mineral

ii. Some such agencies include National Aluminium Company Limited (NALCO), Bhubaneswar; Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC), Nagpur; National Institute of Rock Mechanics (NIRM), Kolar; Non-Ferrous Technology Development Centre, Hyderabad production and mining policies. Following table gives a broad idea about locations where some strategic minerals are available, but excavation is a difficulty:

Type of strategic material	**Region**
Beryllium	Jharkhand, Odisha
Tin	West Bengal
Tungsten	Chhattisgarh, Jharkhand
Cobalt	Odisha
Gallium	Odisha

At present, India's import dependency is mainly on states such as China, Brazil, Democratic Republic of Congo (DRC), Russia, Australia and the US. Geopolitical factors could impact such bilateral arrangements from time to time. India has considerable dependence on DRC for mineral imports. Unfortunately, DRC is one country with maximum political turbulence. Hence, the internal situation in that country could have an impact on India's import needs.

India's import dependency is mainly on states such as China, Brazil, Democratic Republic of Congo (DRC), Russia, Australia and the US.

Internally too there are new challenges. India has a very high percentage of open pit mining. Opencast or open pit mining is a method in which extraction of a mineral is done near the surface of the earth, creating large open pits. Being cost-effective, this is a very popular method. This activity presents enormous social and environmental challenges that need to be addressed.

India was one of the early investors in the arena of REE and the Indian Rare Earths Ltd. was established in the 1950s. This organisation has four production plants and is profit-making. However, due to limited natural availability of the deposits of the REEs, India has not achieved much in this field. More importantly, it was also realised that importing these minerals from China is much cheaper than to undertake domestic production. However, having realised the importance of the REEs for its strategic industry, India has now started looking at this issue differently. At the same time there is a need to realise that enhancing strategic minerals production would need private industry's support. The country has deposits of rare earths minerals like ilmenite, sillimanite, garnet, zircon, monazite and rutile, collectively called Beach Sand Minerals (BSM). India has almost 35 per cent of the world's total beach sand mineral deposits. Their importance lies in their unique electronic, optical and magnetic characteristics, which cannot be matched by any other metal or synthetic substitute.[29]

The non-availability of minerals owing to unequal distribution or because of other reasons requires alternative mechanisms to overcome the deficit. There are two important options on the table with universal acceptance. One, is the recycling of minerals, and the other is the finding of substitutes (alternative minerals). Effective mechanisms are already in place for the recycling of basic metals (such as iron, nickel, chromium, copper and aluminium).[30] However, this is not yet the case with precious metals and rare earth metals. Identifying substitutes for some of the strategic minerals is essential, but this not a very easy process.

Conclusion

It is difficult to have a universal definition of strategic minerals. India would be required to have its own conceptualisation of its strategic minerals. Strategic industry is growing in India and the need for strategic minerals is expected to increase. India has already identified a few minerals, which it feels are strategic in nature. However, there is a need to undertake a systemic risk analysis for appreciating the present and future needs. This process needs to remain dynamic since the 'topology' of strategic minerals could shift.

There is also a need to develop a practice of risk assessment and devising management strategies for key strategic materials for the present and future. The entire domain of undertaking assessments, factoring strategic needs, managing domestic production and deciding on export/import policies would be a complex and multidisciplinary task. Hence, it is important to evolve a separate structure within the government apparatus (along with the members from industry) for undertaking this task.

India is a mineral-rich country and generally, availability is not an issue. However, the real challenge is that of excavation and processing. For this purpose, some major investments need to be made. Since returns on such investments would take time to materialise there is a need for the government to device a specific industry policy for this sector. Unfortunately, policies like the one for Beach Sand Minerals (BSM), which was announced in August 2018, lack industry focus.

China is the global leader in the REE sector (has around 95% of the global deposits) and is likely to remain so for quite some time. There is an increasing realisation globally about the Chinese monopoly in this sector. Most of the REEs are strategic minerals. India therefore needs to focus more on the development of this sector. Studies should be undertaken to explore the nature of the existing supply-chain mechanism with major emphasis on weapon-specific supply-chain mechanisms. This could help to correctly identify India's country specific dependence. Efforts should be made to reduce large dependence on any specific country.

The role of the private sector in mining and the minerals sector will increase in the years to come. There is a need to increase the research focus in all relevant areas of technology and to undertake research on recycling of minerals and finding the correct substitutes (device material substitution strategies).Effort should be made to reduce the import dependency of technologies too. Unfortunately, geological and material sciences are not popular areas of research in India. Industry would require not only modern technology but also trained manpower. As a way forward, it is important to evolve an eco -system involving government agencies, public sector undertakings, private industry and educational organisations.

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