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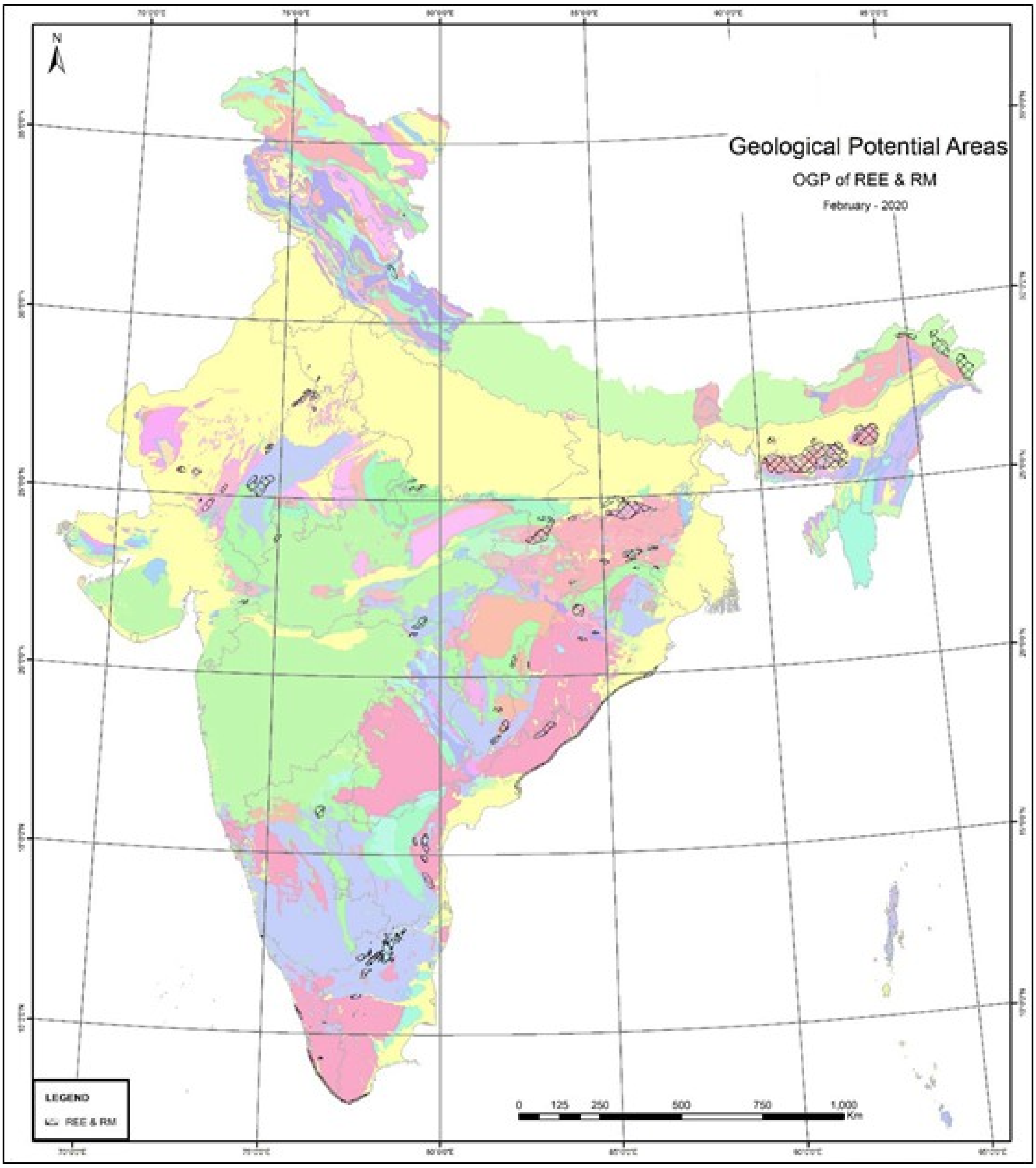
Strategic Plan for Enhancing REE Exploration in India



Geological Survey of India
&
Atomic Minerals Directorate for Exploration and Research

November 2020

STRATEGIC PLAN FOR ENHANCING REE EXPLORATION IN INDIA

Abstract

This special issue deals with REE mineralization and its exploration strategy in India. It includes outcome of studies mainly carried out by the Geological Survey of India (GSI), Atomic Minerals Directorate for Exploration and Research (AMD) and some of the published literatures on fundamental aspects on REE. Collective results of cumulative work by GSI and AMD provide a new insight into the geological, geochemical, geophysical and temporal characteristics of REE mineralization, leading to enhanced understanding of diverse tectono-magmatic, suitable supergene environment and refining of exploration strategies for targeting REE mineralization, within different geological terrains of the country. Although rare earths are relatively plenty in the earth's crust, because of their geochemical characteristics with other minerals, dispersed nature and rarity of economically exploitable primary forms, only a few economically exploitable primary deposits are known. The exploration efforts in the country are to discover a primary deposit and also to identify secondary deposits of exogenic nature. GSI have been acquiring geochemical, geological and geophysical [ground and air] data for the entire mappable part of the country. Till March, 2020 GSI has covered 11.72 lakh sq. km, 7.66 lakh sq. km and 2.66 lakh sq. km area through geochemical, geophysical and aero-geophysical survey respectively. This baseline geoscience data will be of immense use for REE and Rare Metals (RM) mineral prognostication. This document provides an overview on geochemical frameworks, mineralogy, genetic aspects, future strategy and summarizes the exploration history. This issue deals only with Rare Earth elements and exploration on Rare Metals (RM). However, information on RM, wherever available, is incorporated in this document. Although pegmatites are ideal host for economic concentrations of Rare Metals like Columbite-Tantalite (Nb-Ta minerals), beryl, chrysoberyl (Be-mineral) and Lepidolite, Spodumene, Ambligonite (Li Minerals) and do contain significant REE concentrations at places but these REEs are economically not feasible for exploitation.

I - Introduction

The REEs are a group of seventeen metals that comprise the lanthanide series of elements: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), in addition to scandium (Sc) and yttrium (Y), which show similar physical and chemical properties to the lanthanides. Over the last two decades, the global demands of REE have significantly increased with their sudden expansion into high-technological, environmental, and economical environments. The fifteen lanthanide elements have been further subdivided into the: 1. light-rare-earth elements (LREE)—lanthanum, cerium, praseodymium, neodymium, promethium, samarium, and europium; and 2. Heavy-rare-earth elements (HREE)—gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Rare Earth Elements (REE) are characterized by high density, high melting point, high conductivity and high thermal conductance.

All REEs occur in nature but not in pure metal form, although Promethium, the rarest, only occurs in trace quantities in natural materials as it has no long-lived or stable isotopes. The estimated average concentration of the REE in the Earth's crust ranges from around 130 µg/g to 240 µg/g which is significantly higher than other commonly exploited elements, and much higher than their respective chondritic abundances. Table 1 presents the average abundances of REE (in µg/g) in Earth's crust in comparison with chondritic abundances.

Table 1. Average abundances of REE (in µg/g) in Earth's crust in comparison with chondritic abundances.

Elements	Taylor and MeLennan (1985)	Wedepohl (1995)	Lide (1997)	Chondritic abundances	
				Wakita et al. (1971)	Pourmand et al. (2012)
La	16.0	30	39	0.34	0.2469
Ce	33.0	60	66.5	0.91	0.6321
Pr	3.9	6.7	9.2	0.121	0.0959
Nd	16.0	27	41.5	0.64	0.4854
Sm	3.5	5.3	7.05	0.195	0.1556
Eu	1.1	1.3	2	0.073	0.0599
Gd	3.3	4	6.2	0.26	0.2093
Tb	0.6	0.65	1.2	0.047	0.0378
Dy	3.7	3.8	5.2	0.30	0.2577

Elements	Taylor and MeLennan (1985)	Wedepohl (1995)	Lide (1997)	Chondritic abundances	
				Wakita et al. (1971)	Pourmand et al. (2012)
Ho	0.8	0.8	1.3	0.078	0.0554
Er	2.2	2.1	3.5	0.20	0.1667
Tm	0.3	0.3	0.52	0.032	0.0261
Yb	2.2	2	3.2	0.22	0.1694
Lu	0.3	0.35	0.8	0.034	0.0256
Y	20.0	24	33	-	1.395
Sc	30.0	16	22	-	5.493
Total	**136.9**	**184.3**	**242.17**		**9.5118**

The REE-bearing minerals are diverse and often complex in composition. At least 245 individual REE-bearing minerals are recognized; they are mainly carbonates, fluorocarbonates and hydroxylcarbonates (n=42); oxides (n=59); silicates (n=85); and phosphates (n=26). The rare earths found associated with many other minerals and are recoverable as by-products from phosphate rock and from spent uranium leaching. In India, monazite is the principal source of rare earths and thorium. REE occurs as a trace element in many minerals. The principal sources of rare earth elements are bastnaesite (a fluoro-carbonate which occurs in carbonatites and related igneous rocks), xenotime (yttrium phosphate) commonly found in placer deposits, loparite which occurs in alkaline igneous rocks and monazite (REE-Th Phosphate).

Table 2. Rare Earth Element bearing minerals.

Mineral	Mineral chemistry	wt % REO
Oxide		
Ancylite (Ce)	$SrCe(CO_3)_2(OH)\ H_2O$	46 to 53
Brannerite	$(U,Ca,Y,Ce)(Ti,Fe)_2O_6$	6
Calcio–ancylite (Ce)	$(Ca,Sr)Ce_3(CO_3)4(OH)_3\ H_2O$	60
Cerianite(Ce)	$(Ce^{4+},Th)O_2$	81
Cerite(Ce)	$Ce_9^{3+}Fe^{3+}(SiO_4)_6[SiO_3(OH)](OH)_3$	60
Cheralite (Ce)	$(Ce,Ca,Th)(P,Si)O_4$	5
Churchite (Y)	$YPO_4\ 2H_2O$	44
Eudialyte	$Na_4(Ca,Ce)_2(Fe^{2+},Mn^{2+},Y)ZrSi_8O_{22}(OH,Cl)_2$	1 to10
Euxenite (Y)	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$	<40
Fergusonite (Ce)	$(Ce,La,Y)NbO_4$	47
Loparite (Ce)	$(Ce,Na,Ca)(Ti,Nb)O_3$	32 to 34

Perovskite	$(Ca,REE)TiO_3$	≤37
Samarskite (Y)	$(Y,Ce,U,Fe^{3+})_3(Nb,Ta,Ti)_5O_{16}$	12
Thalénite (Y)	$Y_3Si_3O_{10}(OH)$	63
Yttrotantalite (Y)	$(Y,U,Fe^{2+})(Ta,Nb)O_4$	<24
Carbonate		
Bastnäsite (Ce)[2]	$(Ce,La)(CO_3)F$	70 to 74
Huanghoite (Ce)	$BaCe(CO_3)_2F$	38
Kainosite (Y)	$Ca_2(Y,Ce)_2Si_4O_{12}(CO_3)\ H_2O$	38
Hydroxylbastnäsite (Ce)	$(Ce,La)(CO_3)(OH,F)$	75
Parisite (Ce)	$Ca(Ce,La)_2(CO_3)_3F_2$	59
Synchysite (Ce)	$Ca(Ce,La)(CO_3)_2F$	49 to 52
Silicate		
Allanite (orthite)	$(Ce,Ca,Y)_2(Al,Fe)3(SiO_4)_3(OH)$	3 to 51
Britholite (Ce)	$(Ce,Ca)_5(SiO_4,PO_4)_3(OH,F)$	56
Gadolinite	$(Ce,La,Nd,Y)_2Fe^{2+}Be_2Si_2O_{10}$	40
Mosandrite	$(Na,Ca,Ce)_3Ti(SiO_4)_2F$	<65
Titanite (sphene)	$(Ca,REE)TiSiO_5$	≤3
Zircon	$(Zr,REE)SiO_4$	<5
Phosphate		
Monazite (Ce)	$(Ce,La,Nd,Th)PO_4$	35 to 71
Xenotime (Y)	YPO_4	52 to 67
Fluorapatite (Ce)	$(Ca,Ce)_5(PO_4)_3F$	0 to 21
Fluorite	$(Ca,REE)F$	

[Source: Habashi (1994); Long et al. (2010); mindat.org (http:// www. mindat.org /index.php); and Hoatson, et al., 2011]

The REEs have moderate electronegativity between 1.0 and 1.2 duly forming bond with an elevated ionic component. The trivalent ions have nearly identical chemical behavior thus being very difficult to separate each other in the laboratory. Minerals, however, can fractionate them according to their ionic radii. In general, the feldspars have a marked preference for the lightest $LREE^{3+}$ and Eu^{2+} whereas the ferromagnesian minerals either prefer the $HREE^{3+}$ (garnet, zircon) or are little selective (amphibole, clino-pyroxene). Remarkably, the REE except Eu tend to form minerals of their own, phosphates, silicates, niobotantalates, carbonates, etc.

The REE are more abundant than other better known but more conspicuous elements such as Pb, Sn, Au, etc. Their relative proportions in the Silicate Earth (or Primitive Mantle) are identical to the proportions found in the carbonaceous chondrites (Table 1) which represent undifferentiated material similar to the one that formed the Earth. Geochemically, therefore, they are lithophile refractory elements.

The Rare Earth Elements geochemistry is a powerful petrogenetic tool which wisely used may result in great interpretations. The rule of thumb is to consider that the REEs:

- In mantle-derived rocks and magmas, the REEs give information about the behavior of major phases during partial melting and crystallization.
- In crustal mafic-to-intermediate systems the REEs also give information about the behavior of major phases, but the role of apatite, titanite, epidote and allanite must also be considered.
- In crustal felsic and metapelitic systems, the REEs give information mostly about the behavior of accessory phases and the interplay between these and the major minerals.

The prominent industries where REEs find applications are catalysts (24%), magnets (23%), polishing (12%), other applications (9%), 8% each in metallurgy and batteries, glass (7%), ceramics (6%) and phosphors and pigments (3%). Rare earth materials are utilized in a wide range of critical products enabling many emerging green energy technologies, high tech applications and defence systems etc. The lanthanide elements as a group have magnetic, chemical and spectroscopic properties that have led to their application in wide range of end-uses. Some examples of how REE are being utilized and its applications are given below.

Table 3. Some examples of how REE are being utilized in the world today in different areas

Area	Applications
Electronics	Television screens, computers, cell phones, silicon chips, monitor displays, long-life rechargeable batteries, camera lenses, light emitting diodes (LEDs), compact fluorescent lamps (CFLs), baggage scanners, marine propulsion systems
Manufacturing	High strength magnets, metal alloys, stress gauges, ceramic pigments, colorants in glassware, chemical oxidizing agent, polishing powders, plastics creation, as additives for strengthening other metals, automotive catalytic converters
Medical Science	Portable X-ray machines, X-ray tubes, magnetic resonance imagery (MRI) contrast agents, nuclear medicine imaging, cancer treatment applications, and for genetic screening tests, medical and dental lasers
Technology	Lasers, optical glass, fiber optics, masers, radar detection devices, nuclear fuel rods, mercury-vapor lamps, highly reflective glass, computer memory, nuclear batteries, high temperature superconductors
Renewable Energy	Hybrid automobiles, wind turbines, next generation rechargeable batteries, biofuel catalysts

Area	Applications
Others	The europium is being used as a way to identify legitimate bills for the Euro bill supply and to dissuade counterfeiting. An estimated 1 kg of REE can be found inside a typical hybrid automobile Holmium has the highest magnetic strength of any element and is used to create extremely powerful magnets. This application can reduce the weight of many motors

The objective of this document is

a) To provide an overview of domestic reserves and resources of REE in India;
b) Intensify REE exploration in already known geological domains;
c) Identification of new target areas for REE exploration and
d) To take up Research and Development (R&D) programmes to overcome challenges related with exploration and data evaluation, besides beneficiation of REE in cost effective way from already known resources.

At present, India obtains its REE raw materials from foreign sources, from Canada, Russia and China. This report restates basic geologic facts about REE, current knowledge of domestic resources, and possibilities for future domestic production. Further detail follows in a deposit-by-deposit review of the most significant domestic REE deposits (see index map). Necessary steps to develop domestic resources are discussed in a final section, leading into a review of current domestic exploration and a discussion of the value of a future national mineral resource assessment of REE.

II - Classification of REE Deposits

REE concentrations occur in diverse geological settings and due to overlapping imprints of geological processes it is difficult to classify them clearly. REE deposits can be formed by various igneous, sedimentary, hydrothermal, hydrogenous and supergene processes. Deposits that supply rare earth resources can be divided into two categories; igneous deposits formed by igneous rocks or associated hydrothermal activity and weathering deposits formed from weathered rocks. Cases of igneous deposits include carbonatites, alkaline rocks and hydrothermal iron oxide deposits. The broad classification of REE deposit types is furnished below.

Table 4. Classification of REE deposit types

Deposit type	Brief description	Typical grades and tonnage	Major examples
Primary deposits			
Carbonatite-associated	Deposits associated with carbonate-rich igneous rocks associated with alkaline igneous provinces and zones of major faulting	A few 10s thousands of tonnes to several hundred MT, 0.1–10% REO e.g. Bayan Obo: 750 MT at 4.1% REO	Mountain Pass, USA; Bayan Obo, China; Okorusu, Namibia; Amba Dongar, India; Barra do Itapirapuã, Brazil; Iron Hill, USA
Associated with alkaline igneous rocks	Deposits associated with igneous rocks characterized by abundant alkali minerals and enrichment in HFSE	Typically <100 MT (Lovozero >1000 MT), grade variable, typically <5% REO e.g. Thor Lake: 64.2 MT at 1.96% REO	Ilimaussaq, Greenland; Khibina and Lovozero, Russia; Thor Lake and Strange Lake, Canada; Weishan, China; Brockman, Australia; Pajarito Mountain, USA
Iron-REE deposits (iron oxide-copper-gold deposits)	Copper-gold deposits rich in iron oxide and diverse in character and form	e.g. Olympic Dam: 2000 MT at 0.3295% REO (Orris and Grauch, 2002)	Olympic Dam, Australia; Pea Ridge, USA
Hydrothermal deposits (unrelated to alkaline igneous rocks)	Typically quartz, fluorite, polymetallic veins and pegmatites of diverse origin	Typically <1 MT, rarely up to 50 MT, grade variable, typically 0.5–4.0%, rarely up to 12% REO e.g. Lemhi Pass: 39 MT at 0.51% REO (Orris and Grauch 2002)	Karonge, Burundi; Naboomspruit and Steenkampskraal, South Africa; Lemhi Pass and Snowbird and Bear Lodge, USA; Hoidas Lake, Canada

Secondary deposits			
Marine placers (including coastal dune deposits formed by Aeolian processes)	Accumulations of resistant, heavy minerals, concentrated by coastal processes and found along or close to existing coastlines	Highly variable tonnage, commonly in the order of 10s to 1–3 hundred MT, generally <0.1% monazite e.g. Jangardup 30 MT at 0.046% Monazite (Orris and Grauch 2002)	Eneabba, Jangardup, Capel, WIM 150, North Stradbroke Island, Australia; Green Cove Springs, USA; Richards Bay, South Africa; Chavara, India
Alluvial placers	Concentrations of resistant, heavy minerals in river channels	10s to <200 MT, typically <0.1% monazite e.g. Horse Creek: 19 MT at 0.041% monazite (Orris and Grauch 2002)	Perak, Malaysia; Chavara, India; Carolina monazite belt and Horse Creek, USA; Guangdong, China
Paleoplacers	Ancient placer deposits typically forming consolidated, cemented rocks	10s MT up to 100 MT, typically (<0.1% REO)	Elliot Lake, Canada; Bald Mountain, USA
Lateritic deposits	Residual surface deposits formed from intense chemical weathering of REE-enriched igneous rocks	A few 10s thousands of tonnes to several hundred MT, 0.1–10% REO e.g. Mt Weld: 12.24 MT at 9.7% REO (up to 40% REO)	Mount Weld, Australia; Araxá, Brazil; Kangankunde, Malawi
Ion-adsorption clays	Residual clay deposits formed from the weathering of REE-enriched granites	Most <10 000 tonnes, low-grade (0.03–0.35% REO)	Longnan, Xunwu, China
Phosphorite	Phosphorite deposits form as chemical precipitates on continental shelves, REE substitutes for Ca in the mineral francolite $(Ca,Mg,Sr,Na)_{10}(PO_4,SO_4,CO_3)_6F_{2-3}$ Upper Devonian and Mississippian Phosphorites (>380 Ma) up to 18000 ppm REE Nearly 100% extractable with dilute acid	REE contents of phosphorite worldwide are mostly within 0.5%.	Florida/Idaho/mid west

Sea floor bed/mud	Several types of seafloor sediment harbour high concentrations of REEs. However, seafloor sediments have not been regarded as a rare-earth element and yttrium resource, because data on the spatial distribution of these deposits are insufficient. Uptake of rare-earth elements and yttrium by mineral phases such as hydrothermal iron-oxyhydroxides and phillipsite seems to be responsible for their high concentration.		
Industrial Process Residues			
coal fly ash	Fly ash from Coal can be secondary source of REE. For coals with normal REE content, these elements are mainly concentrated in accessory minerals (allanite, monazite, xenotime), resistate minerals (monazite, florence, xenotime, zircon), or clay minerals (kaolinite, illite).		Pennsylvania?
Phosphogypsum	Phosphogypsum (PG) is a by-product of phosphoric acid production via a wet process. In this process, 70–85% of rare earth elements (REEs) originally present in the Phosphate rock is	The REE content of PG significantly varies depending on the origin of the phosphate ore; however, it is typically ca. 0.4%	

	concentrated in the PG. PG mainly consists of calcium sulfate ($CaSO_4$) dihydrate or hemihydrate along with phosphate, fluoride compounds, and silica as the main impurities.		
Red mud	Rare earth elements present in the bauxite residue (red mud) could be a potential resource for the extraction of REEs (Sc, La, Ce). It is difficult to recover REEs directly from red mud due to its low concentration and the Presence of major minerals.		
Slag	The processing of blast furnace slag as a secondary source of REE		

All such REE-repository rock formations of diverse geological ages occur in India. While carbonatites, alkaline rock complexes and beach sands have received adequate attention, the other potential REE-source rocks need a special attention. Rare earth deposits in India are of two major types: endogenic and exogenic. The endogenic types include some carbonatites, alkaline, pegmatitic rocks, metamorphic-metasomatic veins, the exogenic types comprise coastal or beach placer, inland placer and offshore placer. Monazite is the principal ore mineral for REE in India. In development of beach placer deposits, granites, granitic pegmatites, migmatites, gneisses, charnockites, leptynites and khondalites provided the necessary source and the tropical climate with heavy rainfall and strong wave action was especially conducive to the concentration of the placer minerals in suitable locales.

Age Range: The primary REE deposits range in age from Archean to younger igneous activity of post cretaceous. However, most of the exogenic/ secondary deposits fall in the age bracket of tertiary and quaternary.

III - Proposed Exploration Methods

Targeting the host rocks and host material of REE

Geological Survey: Various types of host rocks of REE are planned to be targeted. In this context some approaches may be given for identifying various targets for exploration. As for example, alkaline complexes (plug like bodies can be picked up by Landsat imageries, lineament studies, areas adjoining to known occurrences, etc.), radioactive placers/rocks by airborne radiometric data interpretation, scrutiny of available geochemical data to unravel peralkaline felsic rocks, etc. In what type of tectonic setting IOCG type of mineralisation would be intercepted can be given for targeting this type of REE mineralisation.

Geophysical Survey: Owing to the presence of U and Th in REE deposits, surface or airborne radiometric surveying can be used quite successfully in REE exploration. Discovery of carbonatitic–alkalic hosts of REES can be achieved by the radiometric method. Airborne magnetic, radiometric, and gravity surveys can also be used to delineate host rocks of REE. Ground radiometric and magnetic methods are useful for follow-up surveys. Because many carbonatite complexes are surrounded by mafic alkaline rocks, they often show up as a magnetic bull's eye combined with a gravity low and ringed by a gravity high. GSI has acquired ground geophysical data and aero-geophysical data over an area of 7.66 lakh sq. km and 2.66 lakh sq. km respectively till March, 2020 which will be vital for REE prognostication.

Geochemical Prospecting: Regional geochemical surveys, involving pedogeochemical, lithogeochemical, hydrogeochemical, stream sediment sampling etc, are planned to be carried out to identify targets with the help of distribution pattern of pathfinder elements leading to location of anomalous zones/source rocks etc. The multi-elemental geochemical data acquired by GSI over an area of 11.72 lakh sq. km till March, 2020 will be of immense use for targeting REE mineralization.

Prospecting and Sampling: Pitting and trenching is planned to be undertaken in target areas to acquire information regarding lateral and depth continuity of mieralised zones, dispersion of various elements in soil covered areas in various ('A', 'B' and 'C') horizons etc. Samples generated will be analysed for individual REE and associated elements of interest like U, Th, Nb, Ta, Zr etc. depending on host rocks to also assess for possible by-products/co-products along with REE. Panning of trench pit material give a better control on secondary REE mineralization as well as to delineate the primary mineralized zones for detailed subsurface drilling.

Subsurface Exploration by Drilling and Resources Evaluation: The areas identified by prospecting where results are encouraging in such areas sub-surface exploration by drilling would be taken up by selecting appropriate drilling spacing to trace lateral and depth continuity of mineralisation leading to resource evaluation.

IV - Status of REE Exploration in India

Status of REE Exploration in different parts of India carried out by GSI

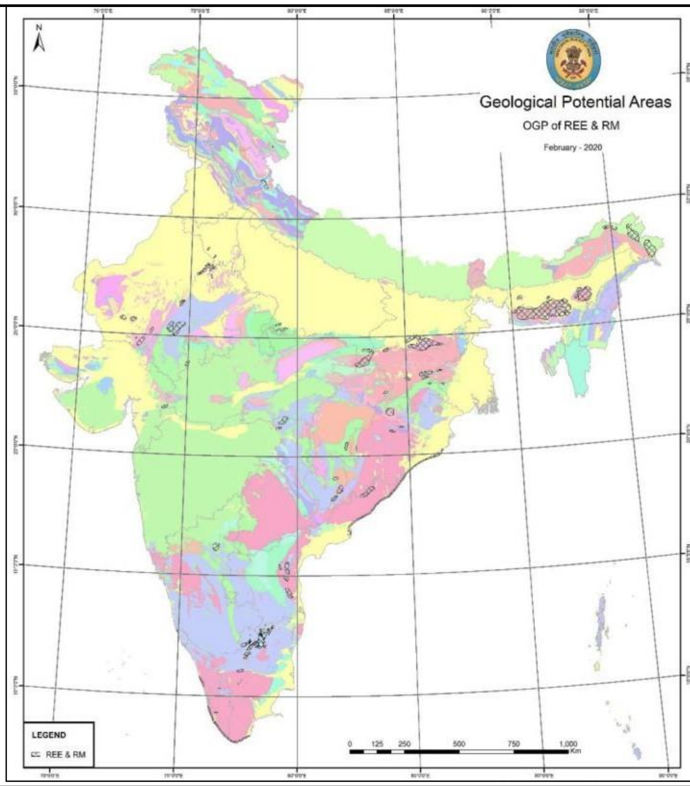
Follow-up on baseline geoscience data and other data generated from the past investigation reports for furthering search of REE has increased understanding on the following areas in India.

In India, REE prospects and occurrences are distributed in the states of Northeastern Region, Rajasthan, Andhra Pradesh, Tamil Nadu, Jharkhand, Odisha, Bihar, Chhattisgarh, Uttar Pradesh, Kerala, Karnataka, Maharashtra, West Bengal, Himachal Pradesh, Madhya Pradesh, Haryana, Gujarat, and Jammu & Kashmir in the order of extent of geologically potential areas.

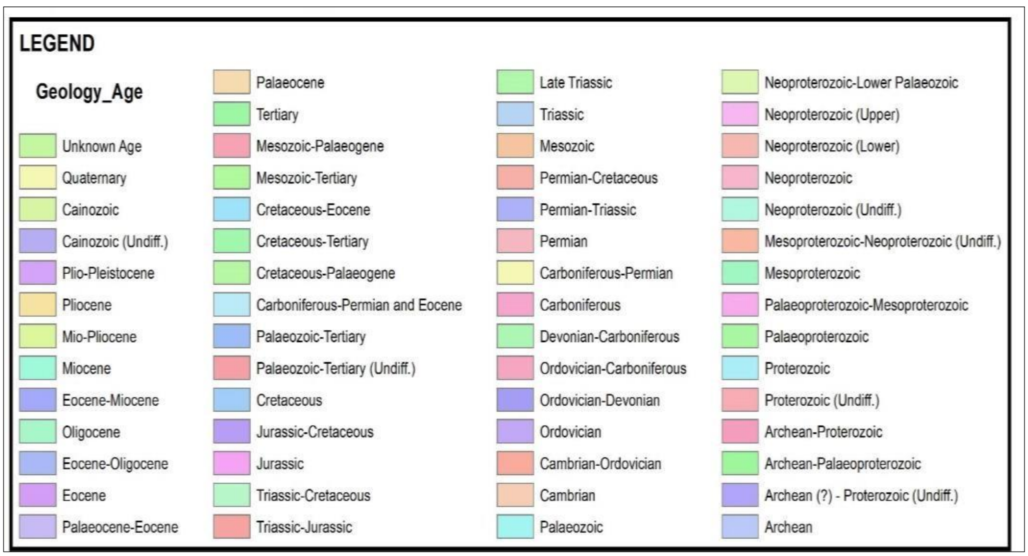
Based on the study and distribution of several prospects and nearly 145 occurrences of REE & RM, its genetic association, geologic set-up, a total of 58,626 sq. km area has been delineated to be potential for REE occurrences in the country. However, with progressive exploration and advances in geoscience research, it is expected to extend the search space for exploration of REE-RM in India.

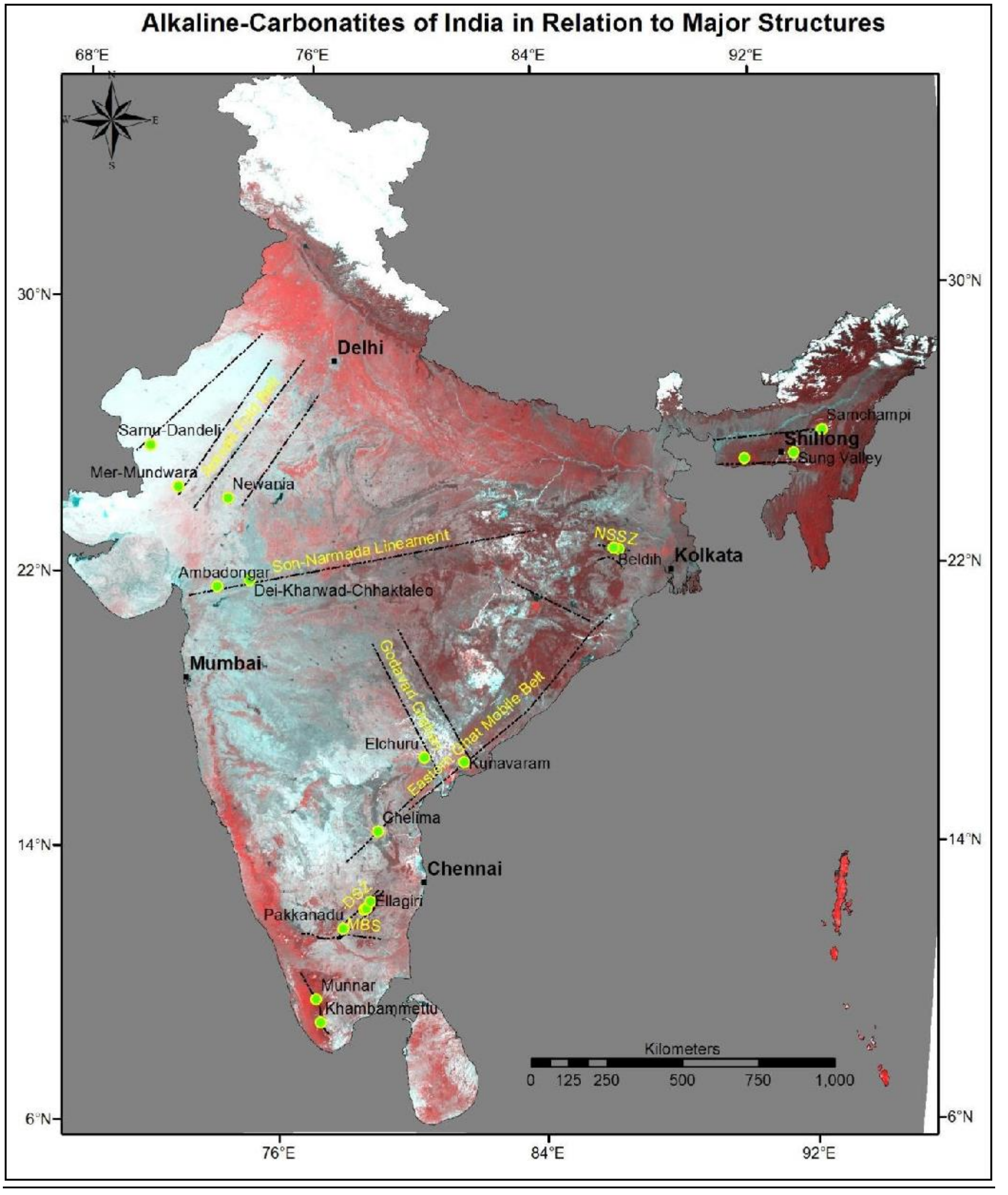
Table 5: State-wise distribution of Geological Potential Areas (in sq. km) for REE

Meghalaya	10398		Uttar Pradesh	2175
Assam	7042		Kerala	1208
Rajasthan	5944		Karnataka	962
Arunachal Pradesh	5607		Maharashtra	918
Andhra Pradesh	5386		West Bengal	756
Tamil Nadu	4514		Himachal Pradesh	605
Jharkhand	3502		Madhya Pradesh	354
Odisha	3182		Haryana	259
Bihar	3133		Gujarat	254
Chhattisgarh	2210		Jammu & Kashmir	29
All India OGP-2020 for REE 58,439 sq. km				

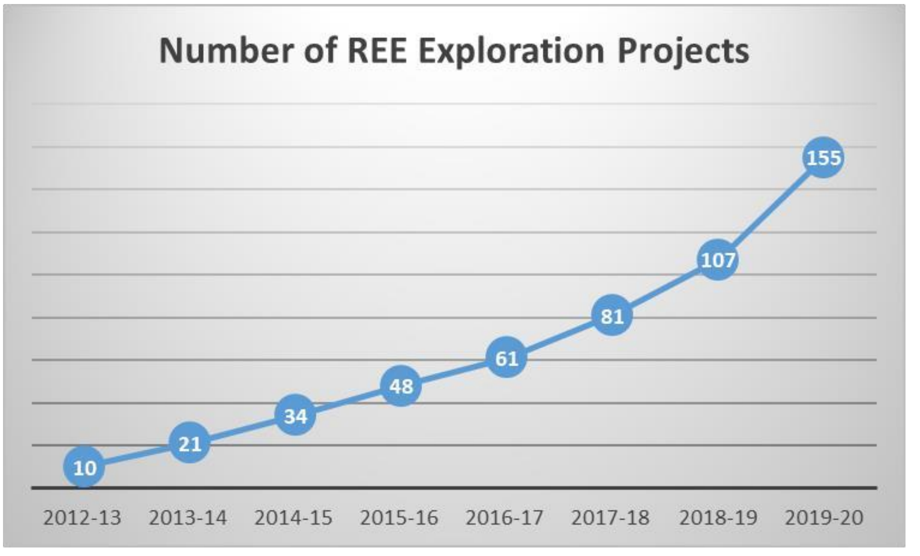


Map OGP-2020: Geological Potential Areas of REE





Exploration Trend: In general, GSI carried out about 14 mineral exploration projects annually from 2012 to 2017. More thrust was given for REE search in the country from the year 2017. More than 20 exploration projects were mounted to enhance the chance of discovery of REE zones in the country from the year 2017 to 2020.



Cumulative Graph of Number of Mineral Exploration Projects by GSI since 2012.

Prospects and Occurrences: Systematic geological mapping, geochemical survey and reconnaissance mineral exploration by GSI has identified many occurrences of REE in the country. These are, Kanigiri granite, Prakasam district, Andhra Pradesh; Samchampi alkaline complex of Assam; Pegmatites of Bihar mica belt; RM bearing pegmatites of Gujarat; RM and REE bearing carbonatites of Gujarat; RM bearing pegmatites of Karnataka; Kolar–Suradevi Block, Maharashtra Borban–Satrapur Block, Maharashtra; Nayakund– Mehandi Block, Maharashtra; Sung Valley carbonatite complex, Jaintia Hills District, Meghalaya; RM bearing pegmatites of Bastar - Koraput - Pegmatite Belt (BKPB); Malani granites of Rajasthan; Pegmatites of Bhilwara mica belt, Rajasthan; Dhani Granite block, Pali District, Rajasthan; Kullampatti – Alasiramani area, Tamilnadu; Dindigul – Anna district, Tamilnadu; Karattupatti village, Madurai district, Tamilnadu; Sankari – Tiruchengode granite, Tamilnadu; A-type granites of Madurai, Tamilnadu; Sevattur carbonatite, Tamilnadu; Samalpatti carbonatite, Tamilnadu; Pakkanadu-Mulakkadu carbonatites, Tamilnadu; Hogenakkal carbonatite complex, Tamilnadu; Carbonatite of Kambammettu area, Kerala; Pegmatites of Chotanagpur Gneissic complex of Purulia district, West Bengal.

Detailed Investigation for Rare Metal (Cs, Li & Rb) of Beku Pegmatite Body by Mineral Exploration Corporation (MECL); Rare Earth Mineral of Nawhatu Area, Purulia district West Bengal etc., in the country. The Iron Oxide Copper Gold mineral systems of Khetri region of Rajasthan and parts of Singhbhum are also the potential targets being searched for REE by GSI and AMD as well. Carbonatite dykes and plugs showing highly anomalous values in selected rock samples were identified around Sarnu-Dandali area in Barmer district in 1990. Kamthai part of the carbonatites have shown enrichment of light REE.

The Siwana Ring Complex, Rajasthan: It is a 750 sq. km geological formation representing a collapsed cauldron ring structure of volcano-plutonic rocks of

Neoproterozoic age. Occurrence of peralkaline granitoid rocks that is known to constitute one of the favorable repositories of REE & RM mineralization. GSI has reported seven parallel NNW-SSW trending felsite dykes within rhyolite porphyry at Phulan that vary in length from 60 to 200m and with width from 0.10 to 2.50m. Bhatikhera prospect lies at the northern margin of the Siwana Ring Complex. It exposes 1.4 km long, 5-20m wide dyke of microgranite/ felsite that analyses high rare earth (inclusive of Y) content. It contains La (842-942 ppm), Ce up to 3.19%, Y (1466-1472 ppm) and other elements like Nb (649-629 ppm) and Zr (12120-12383 ppm). The total HREE content (with Y) is about 0.4%. It may, however, be noted that REE mineralization is often associated with elevated contents of U and Th.

Amba Dongar Carbonatite Complex of Gujarat: Amba Dongar lies in Gujrat and the nearest airport to this is Vadodara. The carbonatite complex of Amba Dongar was emplaced into the northern part of the Deccan Volcanic Province of West-Central India. The economic potential of the complex was first revealed in 1962 with the discovery of large amounts of fluorite by GSI. Large reserves of fluorite deposits, estimated by the GSI as 11.6 million tons averaging 30% CaF_2, are associated with the carbonatites and are presently mined by the Gujarat Mineral Development Corporation. The fluorites are important for the REE potential. The Amba Dongar area is one of the most potential area for REE mineralization associated with barium, niobium and strontium. The LREEs dominate in carbonatites of Amba Dongar Carbonatite Complex. Bastnaesite predominates the hydrothermal assemblage in carbonatites. Parisite and synchysite have been found only as a fibrous fringe between wall rock ankerite and bastnaesite. Such zones are more enriched in LREE amongst all the REE, with high concentration of cerium.

Quartz Vein/Pegmatite/Alkali granite/Syenite: Mincheri Block is located in Lingasugur taluk, Raichur District, Karnataka explored by GSI during 2015-16. The surface manifestation of mineralization was indicated by different alterations like ferruginization, radioactive halos and localization of fine-grained dark minerals in the quartz veins. The mineralization is mostly confined within the quartz reef associated with the hydrothermal fluids emplaced along the N-S trending fault planes. The quartz veins injected within intrusions of alkali rich granite and syenite. Interestingly, REE mineralization is mostly localized within the brecciated quartz vein. In some boreholes the tREE (total REE) values range from 0.05 % to 6.67% with high sulphides concentrations mainly represented by pyrite and chalcopyrite. The eastern most contact of the REE zone, the tREE values vary from 0.05% to 1.277% per 0.5m. Another intersected REE zone in borehole contains anomalous sulphides, feldspars with tREE values range from 0.12% to 6.67%. Similar zones were demarcated in other three boreholes with tREE values ranging 0.03% to 0.288%, 0.08% to 1.55% and 0.056% to 0.081% for every 0.5m. A total resource of 0.714 mt (million tons), 0.620 mt & 0.146 mt with cut-off grade of 0.1%, 0.5% and 1% tREE were estimated under (G3) category.

Saidiwasan carbonatite complex: The Saidiwasan carbonatite complex, Chhota Udepur district, Gujarat belongs to the Chhota Udepur carbonatite alkaline rock provinces. These carbonatites are emplaced in western periphery of the Deccan basaltic provinces which is predominantly tholeiitic in nature. The carbonatite sill at Saidiwasan along with sovite plugs, show varied mineral assemblages, intense fenitisation of enclosed xenoliths and interesting geochemical character. Nephelinites are associated with carbonatites in the Saidiwasan area which have been extensively fenitised. The Saidiwasan Carbonatite Complex is explored by GSI and Atomic Mineral Division since 2014. During FS 2015-16, GSI carried out Reconnaissance survey for REE and RM in Saidiwasan area. Based on the anomalous values of REE and Niobium in the Saidiwasan carbonatite complex a G3 stage exploration is under operation in FS 2019-21 in Manka and Nakhal block of Saidiwasan area.

Minor Occurrences & Prospects of REE in India: GSI has intensified REE exploration in the country from 2017 onwards and details of REE prospects and occurrences identified by GSI are tabulated below.

Table 6. Minor REE Prospects & Occurrences identified by GSI

Geological domain/ Nature of REE Deposit	Area	REE Mineralization and Grade
Carbonatites	RM and REE bearing carbonatites of Gujarat.	Carbonatites show enrichment of LREE over HREE with the ΣREE content ranges from 0.0016 to 0.59%. The Nb values of carbonatites of Saidiwasan –Nakkal area ranges from 155 to >1000ppm. Interestingly, the infra-trappean sandstone also analyses higher REE, Nb and Y contents. Pyrochlore, microlite, sphene, apatite and zircon are the REE bearing minerals found in these rock types.
	Sevattur carbonatite.	The Sevattur carbonatite analyses 1663 ppm of Ba, 6427 ppm of Sr, 763 ppm of Zr, 78 ppm of P_2O_5 and 16 ppm of Sc.
	Samalpatti carbonatite.	In Samalpatti area, the carbonatites occur as lenses mainly within the pyroxenite, the major one extending from Gargipalli to Onnakkarai for a distance of about 2km with width varying from 20 to 150 m.
	Pakkanadu-Mulakkadu carbonatites	These carbonatites are pure calcite rich sovite type with minor variation to biotitic and ankeritic variants. Apatite, magnetite, allanite, barite, monazite, zircon and cerianite are the accessory minerals present in them.
	Hogenakkal carbonatite complex.	The Hogenakkal alkaline complex comprises pyroxenite, syenite and carbonatites, occurring as linear bands and dykes. The total REE content (4653-4741 ppm) of the MAC carbonatite of

		Hogenakkal area is strikingly higher.
	Carbonatite of Kambammettu area	In Southern Tamil Nadu, a small body of carbonatite of magnetite-sovite variety has been located in the foothills, east of Kambammettu in Madurai district.
	Sung Valley carbonatite complex, Jaintia Hills District, Meghalaya.	Carbonatites of Sung Valley complex are mainly sovite with minor beforsite types rich in magnetite and apatite. The sovite variety analyses 154-606 ppm of Nb, 50-100 ppm of Y, 244-471 ppm of Ce, 50-100 ppm of La, 3355-3509 ppm of Sr, 513-525 ppm of Ba, <0.3 to 29 ppm of U and <0.6 to 7.8 ppm of Th. On the other hand, the beforsite variety analyses high Nb (512 ppm) and Ba (622 ppm) and low Y (10-50 ppm), Ce (149 ppm), La (30-50 ppm) and Sr (1399 ppm).
Alkaline complex	Samchampi alkaline complex of Assam.	Samchampi alkali complex in Mikhir hills of Assam has shown occurrences of Nb-Ta minerals.
Pegmatite vein	Pegmatites of Bihar mica belt.	The Bihar mica belt which stretches along WSW – ESE direction for nearly 160 km between Gurpa in Gaya district in the west up to the southern part of Bhagalpur district in the east is prospective for REE.
	RM bearing pegmatites of Gujarat.	Occurrence of REE and RM bearing pegmatites with gadolinite, cassiterite, and tourmaline in Palanpur – Hosainpur area of Gujarat is known for quite some time.
	RM bearing pegmatites of Karnataka.	A zone of RM bearing pegmatites extending over an area of 4 km x 1 km has been delineated in Maralagalla – Allapatna area in the eastern margin of the Karighatta schist belt exposed east of Srirangapatnam.
	Kolar–Suradevi Block, Maharashtra	REE mineralization is associated with pegmatite and foliated granite. The highest concentration of total REE that is found in granite and pegmatite was 2470.48 ppm and 1173.5 ppm respectively in these areas.
	Borban–Satrapur Block, Maharashtra	
	Nayakund-Mehandi Block, Maharashtra.	

	RM bearing pegmatites of Bastar - Koraput - Pegmatite Belt (BKPB).	The pegmatites of BKPB occurring in the southeastern part of the Bastar craton of Central India are associated with tin, niobium, tantalum, beryllium and lithium mineralization in the form of cassiterite, columbite – tantalite, beryl, lepidolite and amblygonite
	Pegmatites of Bhilwara mica belt, Rajasthan.	Detailed petrological studies of part of this pegmatite belt in Ajmer, Bhilwara and Udaipur districts have resulted in classifying them into nine varieties based on their mineral assemblages (Datta, 1986). Among them, the variety showing smoky quartz - cleavelandite – green muscovite association is reported to contain subordinate amounts of tourmaline, beryl and columbite – tantalite.
	Kullampatti – Alasiramani area, Tamilnadu.	A zone of six parallel to sub-parallel discontinuous bodies of ENE-WSW trending leucocratic pegmatite analyze elevated values of Nb, Ta, Y, Zr, Sr, and Rb.
	Dindigul – Anna district, Tamilnadu.	The REE and RM bearing mineral phases identified in pegmatites with columbite – tantalite, allanite and samarskite association.
	Karattupatti village, Madurai District, Tamilnadu.	An occurrence of beryl and gadolinite bearing pegmatite has been reported near Karattupatti village.
	Pegmatites of Chotanagpur Gneissic complex of Purulia district, West Bengal.	Rare Metal exploration was carried out by GSI for Cesium within the fertile Pegmatites bodies at Beku, Belamu, and Khatanga areas of Chhotanagpur Gneissic Complex, Purulia District. Possible category resource of Cesium was estimated at 0.3%, 0.1% and 200 ppm cesium cut-offs.
	Detailed Investigation for Rare Metal (Cs, Li & Rb) of Beku Pegmatite Body by MECL.	During the period from November 2001 to November 2003, detailed exploration for an area of 1 Sq.km to assess the Beku Rare Metal (Cs, Li & Rb) Prospect, Purulia District West Bengal was carried out by Mineral Exploration Corporation Limited (MECL).
Granites	Malani granites of Rajasthan.	The granites of Malani igneous suite of Rajasthan show anomalous RM and REE values.
	Dhani Granite block, Pali, Rajasthan.	The samples analyzed from four boreholes shows ΣREE varies from 0.106% to 0.2075%.

	Sankari-Tiruchengode granite, Tamilnadu.	In the Sankari-Tiruchengode area, the Na_2O rich leuco granitoids show enrichment of RM (Nb, Ta, and Y), U, Th and HREE while the K_2O rich pink granites show enrichment of Th and LREE in zones rich in allanite.
	A-type granites of Madurai, Tamilnadu.	AMD has located certain RM and REE bearing pegmatites spatially related to a granite body near Nagamalai – Minakshipuram areas in Madurai district.

Status of REE Exploration in different parts of India by AMD

i. REE potential exploration domains and **deposits which categorizes for compliance under AMCR-2016** owing to presence of prescribed substances (U, Th, Nb-Ta etc.) as per Atomic Energy Act 1962 **should be identified and explored by Government agencies.**

ii. Major parts of AMD's REE resources are confined to **the shoreline beach sand placers including Teris/Red Sediments** along the east and west coast of India. These placer contain concentrations of seven important heavy mineral suits viz. monazite, zircon, garnet, ilmenite, rutile, leucoxene, and sillimanite.

iii. AMD has been carrying out its resource evaluation for over seven decades. **Large resources of REE (predominantly LREE) are locked up in monazite bearing beach sands** in coastal regions in peninsular India and **also in the inland alluvium placers** in Ranchi (Jharkhand) and Purulia (West Bengal). Monazite contains around 42-65% REE oxides (95 to 98% LREE with minor HREE). REE resources are mainly distributed in the states of Andhra Pradesh, Odisha, Tamil Nadu, Kerala, West Bengal, Jharkhand etc. The mineral **monazite is a prescribed substance** as per the notification under the Atomic Energy Act, 1962. It occurs in association with other heavy minerals such as ilmenite, rutile zircon, etc. in variable concentrations ranging near negligible to 10.06% of total heavies in the beach and inland placer deposits of the country.

iv. The **Xenotime rich riverine placers** (along with Monazite, Garnet and Ilmenite) along Siri River, Deo River, Mahan Rivers etc. in Eastern India developed over CGGC and the placers along Vasava Nadi, Gujarat developed over Godhra granite are prime sources of HREE. Xenotime contains around 55-70% REE oxides (predominantly HREE & Y: 90 to 97% with minor LREE). Xenotime bearing polymineral concentrates are being recovered (6-7 tonnes per annum) from riverine placers in Jashpur district, Chhattisgarh.

v. Monazite resource from beach and inland placers have been augmented from 11.93 MT in 2012 to **12.47 MT** in 2016 (IBM year book- 2018) and further exploration is in progress.

vi. In hard rock terrains, **AMD is presently exploring their first order target areas at Ambadongar Carbonatite Complex,** Chhota Udepur district, Gujarat and in **Siwana Ring Complex**, Barmer district, Rajasthan.

vii. **Ambadongar-Kawant-Panwad tract** is a classic carbonatite-alkali rock complex, emplaced in close proximity to north of Narmada Rift zone and includes sovite (calcium carbonatite), ferrocarbonatite (Fe-Mg-Mn carbonatites mainly ankeritic), siderite (Fe carbonatite), carbonatite breccia (mixed rock fragments with carbonate cement) etc. Plugs of ankeritic carbonatite intrude the Sovite, which forms a large ring-dike (nearly 1.5 km dia.). Ankerite, Sovite and carbonatite breccia rocks of the ring complex contain significant quantity of REE - categorically LREE (La, Ce, Pr, Nd, Sm) minerals: Bastnaesite, Fluocerite, Synchysite, Pyrochlore, Biraite, Allanite and Monazite of ultra-fine size (2-10gm) along veins/as disseminations in carbonates; In addition Niobium (Nb), Thorium (Th), Barium (Ba), Magnesium (Mg), Vanadium (V) and Strontium (Sr) are present in appreciable quantity. **AMD has established = 3,46,000t REO at 0.5% cut off grade** over an area of 0.625 Ha in the western part of the Carbonatite complex. Resources are likely to enhance with drilling continuing in the area. The Ambadongar deposit has 0.076% Nb_2O_5 (higher than 0.01% Nb_2O_5) and 0.026% ThO_2 (higher than 0.025% ThO_2) which categorize the deposit for compliance under AMCR-2016 as these associated minerals are prescribed minerals.

viii. In **Siwana Ring Complex (SRC) in Barmer district of Rajasthan**, AMD is working in the area since 1996. Exploration has been intensified since 2012-13 which resulted in delineation of five potential areas namely Dantala, Bhatikhera, Phulan, Ramaniya and Nal. Drilling is continuing in Bhatikhera and Ramaniya areas to prove more REE - Nb resources in Siwana Ring complex. GSI is not working presently as per their field season programme (FSP) 2019-20. Moreover, Siwana Ring Complex area shows 0.05% Nb_2O_5in general which makes them to be governed by AMCR 2016. AMD is likely to establish resources in this belt but of lower grade z 0.5% REO (t) than Ambadongar carbonatitie complex (>2% REO t). However, it is pertinent to mention here that, the HREE in the prospect areas of Siwana Ring Complex is in the range of 35 — 40% of the total REE, which normally occur in the range of 10-15% as in Ambadongar**. REE resource of > 1 lakh tonnes is inferred** from this area and work is on progress.

ix. AMD is also exploring other areas in **Buriwara, Mawri and Magreshwar areas in Siwana Ring Complex**, Rajasthan and in several **potential Carbonatite Complexes**- viz. **Saidawasan, SirwanNakal and Pannad-Kuwant complexes** in Chhota Udepur district, Gujarat; **Pakkanadu Mulakkadu complex**, Salem district, Tamil Nadu; **Niwania** in Udaipur District and Mer-Mundwara complex in Sirohi district, Rajasthan.

Apart from the first order target domains, AMD has identified some **potential future target / Greenfield areas for REE exploration** which need to be developed by further exploration. Further, investigations for possible **recovery of REE from non-conventional sources** has identified the residues include phosphogypsum, phosphoric acid, coal fly ash, bauxite residue (red mud), mine tailings, metallurgical slags, waste water streams and recycling of waste electrical and electronic items containing REE as potential secondary resources of REE. We need to encourage technospheric mining to optimize REE recovery from secondary industrial process residues including recycling REE-bearing products.

Table 7. Potential Greenfield geological domain/areas for REE exploration and possible non-conventional sources of REE in India (based on AMD unpublished reports and cited references).

Geological domain/ Nature of REE Deposit	Area	REE Mineral	Grade	Speculative Resources
Carbonatite	Pakkanadu-Mulakkadu, Salem district, Tamil Nadu	Monazite, bastnaesite, cerianite, allanite	1.48% TREE (LREE rich); Anomalous Sc in Bio Schist (Av. 161 ppm)	
	Mer-Mundwara, Sirohi district, Rajasthan		210-340 ppm La; 330-470 ppm Ce; 50—104 ppm Y	
	Niwania, Udaipur district, Rajasthan	Pyrochlore	40-990 ppm La; 220-2690 ppm Ce; 10 ppm Y	
	Siriwasan-Nakal, Chhota Udaipur district, Gujarat	Pyrochlore, apatite bastnaesite, monazite	0.033-0.047% Ce, 0.021-0.03% La; 0.008-0.01% Y and 0.1% Nb_20_5	
	Samchampi deposit, Karbi Anglong district, Assam	Pyrochlore, crandallite, apatite	0.037-0.813% (Av. 0.12%) TREE; Ce > La > Nd & Sm > Y>Gd	3644 t Y in 41.88 mT ore (Av. Grade 88gm/t)
	Samalpatti, Dharampuri district, Tamil Nadu	Bastnaesite, monazite, fergusonite, chevkinite, allanite	8.2 % TREE	
	Sung valley, Jaintia Hills, Meghalaya		0.024-0.047 Ce, 0.005-0.010 Y; Ce>Y	
	Sevattur, North Arcot district, Tamil Nadu	Uranopyrochlore	0.199% TREE; Ce>La>Y	

	Beldih-Kutni, Purulia district, West Bengal	Monazite, apatite	0.144 - 2.43% TREE (Ce > La > Nd monazite)	
Hydrothermal veins	Kanyaluka-Khadandungri, Singhbhum district, Jharkhand	Xenotime, apatite	32.7 % HREE, low LREE Y > Yb> Dy> Er > Gd > Lu	600 tonne Xenotime
	Apatite-magnetite veins, Kasipatnam-Narasimha-rajpuram, Visakhapatnam district, Andhra Pradesh	Apatite, allanite and fluorapatite	1.09-2.35 % REE	3000-4000 tonne
	South Purulia Shear Zone, West Bengal	Fluorapatite, allanite, monazite, xenotime	La 0.112%; Ce 0.1825%	
	Southern part of Kotri Dongargarh belt	Ferruginous brecciated quartz veins	REE+Y:89-58038 ppm, LREE: 63-48840; HREE: 5-15483ppm; Y: 10-18130ppm	
Peralkaline Granite	Cluster of occurrences in Siwana Ring Complex-Ramaniya, Bhatikhera, Nal areas, Barmer district, Rajasthan	Allanite, REE silicates, xenotime, monazite	0.46 - 0.60 % TREO 16, 19-22 Y > La > Nd > La > Gd >Dy> Sm	> 1 Million tonne TREO
	Kanigiri granite, Prakasham district, A.P.	Fergusonite, allanite, bastnaesite, zircon	0.069 TREE ce > Y > La > Nd	
	Dongargrh A-type Granite, central India	Allanite, zircon, apatite	0.0358% TREE	

	Nongpoh, Meghalaya	Allanite, monazite, zircon, apatite	0.083% TREE+Y+Sc Ce > La > Nd > Y>Sm	
	Kumarkunti-Jharnomal, Nuapada district, Odisha	Thorite, allanite, zircon, fersmite	120-1231 ppm Y; 129-1757m La; 453-1876m Ce	
Quartz vein/ Pegmatite	Mincheri, Raichur district, Karnataka	Yttrofluorite, gadolinite, britholite, cerianite, allanite, monazite, bastnaesite	0.135-19.62% TREE	
Riverine / Stream Placers derived from granitic rock	Ib River Basin, Jashpur District, Chhattisgarh. Riverine placer bodies along Siri river, Champajharia, Baljora and Dhob nalas	Xenotime & Monazite	3.9-5.47% Y_2O_3, 2.1-2.9% HREO, 18.8-22.4% LREO	
	Deo River Basin, Gumla district, Jharkhand. Riverine placer bodies along Deo, Girmaand Halwai rivers	Xenotime & Monazite	1.02.-2.1% Y_2O_3 and 0.40-10.25% TREO	
	Mahan River Basin, Surguja district, Chhattisgarh. Riverine placer bodies along Mahan river	Xenotime & Monazite	1.02-4% Y_2O_3 0.50-3.9% 0 TREO	
	Ujol-Vasva, Gujarat	Monazite, xenotime, rutile, zircon	0.51-0.96% Y_2O_3	
	Pathapalem, Mahboobnagar, Telangana	Monazite, xenotime, zircon, garnet	0.63-5.26 % Y_2O_3 in panned concentrates	

	Pauni-Tangla, Nagpur district, Maharashtra	Monazite, xenotime	3.59% Y_2O_3 and 13.7% Ce_2O_3 in panned concentrates	
	Dharmawaram, Karimnagar, Telangana	Monazite, xenotime, thorite, zircon	0.19 - 0.40% Y_2O_3 in panned concentrates	
	Goddavaru Stream, Rangampetta, North Arcot District, Tamil Nadu	Xenotime, monazite, allanite, fergusonite, zircon, garnet	0.003-0.034% Y_2O_3 and 0.034-0.35% Ce_2O_3 in panned concentrates	
Inland placer	Ranchi-Purulia, Jharkhand and West Bengal	Monazite, ilmenite, sillimanite, rutile, zircon	Monazite-rich alluvium 0-1m thickness	12.47 Million Tonnes
Beach placers and red sediments/ teri sand	Coastal tracts of Andhra Pradesh, Odisha, Tamil Nadu, Kerala, Maharashtra	Monazite, ilmenite, garnet, sillimanite, rutile, zircon	Monazite content in sand column varies from 0.003% to 5.14% and containing 42% to 65% of REO	
	Narasapur beach placers, West Godavari district, Andhra Pradesh	Xenotime alongeith other BSM	Xenotime content in sand column varies from 0.02% to 0.35%.	
	Coastal tracts of Andhra Pradesh, Odisha and Tamil Nadu	Garnet	REE content in garnet of sand column varies from 225-5300ppm; Y: 252-669ppm; Sc: 93-387ppm	
Granitic soil	Tonnur-Pandavpura, Hassan and Mandya districts, Karnataka	Monazite, xenotime, ilmenite, rutile, zircon	0.25- 1.37% Y_2O_3 in panned concentrates	

	Tirka, Gondia district, Maharashtra	Monazite, xenotime, zircon, rutile	Monazite contains 52.57 63.65% REO and 1.11-3.35% Y_2O_3; Xenotime revealed 41.86% Y_2O_3 and 18.72% REO	
Secondary Resources of REE	Tin slags from Bastar, Chhattisgarh		Upto 1% TREE	
	Coal fly ash from Neyveli Lignite fields, Tamil Nadu		0.20% TREE; Ce >Nd>Y>La	
	Coal fly ash from Ib Valley, Bhubaneshwar, Odisha		0.035% TREE La>Pr>Gd>D	
	Coal fly ash from Ranigunj coal field, Salanpur, Asansol		0.023% TREE, La>Pr>Gd>D	
	Red mud produced by NALCO, HINDALC, INDAL, etc.	Allanite, dissakisite	Av. 0.01% Gd_2O_3 in red mud from NALCO	
Treatment of Other Mine tailings and Slags of India: Blast furnace slags of steel plants. Phosphoric acid from different Fertiliser plants; Tailings from processing phosphate ore (phosphogypsum); Tailings from lead, zinc, copper and sulphur ores.				
Sea bed resources: Manganese nodules & Sea floor sediments ≈500-1000ppm TREE besides Ni, Cu and Mo; Sea bed in the oceans can hold more than 110 trillion tonne of REE, Sea bed under 90 degree East Ridge in the Indian Ocean is a potential REE source.				

V - World and India’s Rare Earth Resources and Production

World Rare Earth Resources and Production

According to estimates by the U.S. Geological Survey, the worldwide reserves of rare earths are approximately 120 million metric tons (USGS, 2019). Most of these reserves are located within China, and are estimated at some 44 million metric tons. The United States also owns significant reserves, which are estimated to be some 1.4 million metric tons. In addition, within the major rare earth holding countries are India, Australia, Brazil and Malaysia. With over 132,000 metric tons produced from mines in 2018, China by far exploited most of its rare earths reserves. China produces most of these amounts in Inner Mongolia. The United States, which is the second largest producer of rare earths from mines, extracted some 26,000 metric tons of these commodities in the same year.

Resources and production of REE in India

Resources: Geological studies indicate that globally over 62% of the REE resources are hosted in carbonatites, 16% in alkaline rock complexes, 15% in iron ore copper gold (IOCG) deposits, 5% in placers and remaining are contained in a typical repository formations (Zhou et al, 2017). Rare earths are relatively abundant in the Earth’s crust, but discovered minable concentrations are less common than for most other ores. World resources are contained primarily in bastnaesite and monazite. Bastnaesite deposits in China and the United States constitute the largest percentage of the world’s rare-earth economic resources, and monazite deposits constitute the second largest segment (USGS, 2017).

REE resources are mainly distributed in the states of Andhra Pradesh, Odisha, Tamil Nadu, West Bengal, Jharkhand etc. The resource estimates of monazite in the beach and inland placer deposits have been enhanced from 11.93 MT in 2012 to 12.47 MT in 2016 **(IBM yearbook 2018)**. These resources are mainly confined to the states of Andhra Pradesh, Odisha, Kerala, Tamil Nadu, West Bengal, Jharkhand etc.

Cumulative graph of REE ore augmented by GSI.

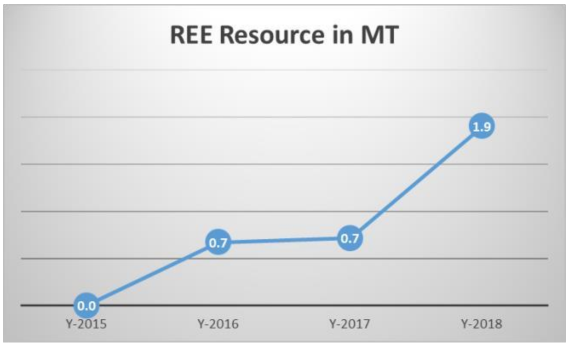


Table 8. REE resources of India estimated by AMD (as per IBM yearbook 2018).

Deposits Type	Domains	Mineralogy	Resource (Million Tonnes)	REO Content (Tonnes)
Hard Rock Carbonatite complex	Ambadongar	Bastnaesite, fluocerite, synchysite, Pyrochlore, Biraite, Allanite, Monazite	25.70 (at 0.5% Cut-off Grade)	
Placer	Coastal and inland placer sands	Monazite	12.47	6,859,300
	Riverine	Xenotime	0. 00004 #	24

2000 t Xenotime bearing polymetallic concentrate containing —2% Xenotime 40 t or 0.00004 mT)

Note: Monazite contain 45-60% REE oxides (55% considered for REO estimation); Xenotime contain around 55-70% REE oxides (60% considered for REO estimation)

Production: IREL (India) Limited, a Mini Ratna (Category-I) CPSE under the Department of Atomic Energy (DAE) is actively engaged in mining and processing of beach sand minerals (Atomic Minerals) from Heavy Mineral Beach Sand deposits. IREL has established the operations since 1952 and is the pioneer in production of Rare Earths and their compounds from Monazite. Rare Earth Extraction Plant (REEP) in Odisha and Rare Earth Division (RED) in Kerala of IREL are successfully producing the Rare Earth Compounds and High pure rare earths from Monazite. IREL has excellent brand equity in the world market owing to the product standards. REEP has the capacity for the production of 11,200 TPA mixed Rare Earth Chlorides (MRCL) from Monazite (5,000 TPA REO) and RED further process the Mixed Rare Earth Chloride to produce separated high pure rare earths (HPRE) such as compounds of lanthanum, cerium neodymium-praseodymium samarium, etc.

VI – Challenges and Way Forward

Exploration: REE metals occur usually in very low concentrations (<1%) in rocks. Hence, these are difficult to locate and identify by normal megascopic and microscopic techniques, which are used in identification of rock–forming minerals that occur in major to minor quantities (>1%). Therefore, these mineral commodities need to be explored with modern concepts and tools for possible breakthrough requiring high investments in sophisticated survey and spatial data management technologies to produce more detailed data and information of areas and depths so far unexplored. Specific and high precision laboratory studies aimed at guiding and substantiating field studies pertaining to ore localization are the need for success exploration for REE minerals.

- Intensified exploration efforts in the blocks delineated in and around the **first order targets areas** by detailed surveys and follow up exploratory drilling.
- All potential blocks in hard rock terrain, viz. Ambadongar Carbonatite Complex, Siwana Ring Complex will be taken up **phase wise for exploratory drilling/sampling and laboratory analysis** for resource augmentation.
- Reconnaitory and detailed surveys will continue in adjoining **Greenfield areas to delineate potential blocks** for follow up drilling and sampling.
- Potential beach sand placer deposits have been identified for exploration up to a depth of 50m utilizing **sonic drilling** to augment additional beach sand heavy mineral resources. In addition, systematic general exploration of **shoreline and inland Teris/Red Sediments** has been planned along the coastal stretches of Odisha, Andhra Pradesh, Tamil Nadu and Kerala. All these exploration inputs are likely to augment the monazite resource in Quaternary deposits.

Beneficiation and Metallurgy (Information from IBMYB 2018): IREL has entered into Memorandum of Understanding (MoU) with BARC, Defence Metallurgical Research Laboratory (DMRL) for manufacturing of Samarium-Cobalt (Sm-Co) Rare Earth Permanent Magnet. IREL under the aegis of DAE is establishing a RE theme park to demonstrate technology developed at BARC at pilot plant level to promote RE value added products. In addition, in order to develop other RE resources, Mineral Processing Division of BARC, Hyderabad (MinD) has carried out metallurgical tests and developed flow sheets at lab scale beneficiation techniques for production of RE-oxalate from the Ambadongar RE ore. Recovery operations for Xenotime bearing polymineral concentrates (7 - 8 tonnes per annum) from potential riverine placers will be continued as these are prime sources of HREE.

Recycling for REEs: REE and rare metal recycling technologies are still in the premature stages of expansion, efforts are likely to continue to help keep pace with the anticipated increase in demand. Recycling of rare earth containing products needs a careful analysis on availability of adequate waste material and apt technologies for economic recovery. Recycling also leads to a reduction in environmental impact due to a possible reduced mining activity. Worldwide, only 1% of the total rare earths in used and obsolete components are being recycled.

Urban Mining: Mining of beach sand minerals will be carried out by IREL/KMML like government organizations, while **IREL-DAE will continue REE recovery from monazite**.

Research and Development: R&D on beneficiation/recovery of REE in cost effective way from known promising carbonatite-hosted REE deposits etc. (e.g. Amba Dongar) will be taken up, as flowsheet for the same has not yet been developed. This work is essential to show that if dependable flow sheet is available, mining operation can be initiated, while resource augmentation is underway. This will reduce time gap between establishing a deposit and initiating mining and commercial production of REE. AMD shall carry out **R&D related to Mineral processing studies** related to development of effective beneficiation and recovery flowsheet of REE, Nb and other associated elements. Garnet, invariably present in BSM suite is a silicate mineral and contains appreciable amount of REE (225-5300 ppm) and HREE content contributes more than 75% of REE. Potential of garnet will be systematically studied under R&D mode as an alternative source for HREE in future in view of large resource base of garnet in the country.

Planning for Next Five Years:

Although exploration for REE has been undertaken in many prospective areas of the country based on the progressive understanding on genetic and mineralization concepts of REE mineralization in space and time, continuous efforts to look for new potential zones with risky exploration is essentially required to meet the REE demand in the country. Identification of HREE deposits and of REE minerals are two of the challenges facing research on REE deposits. The first challenge is to identify and discover deposits capable of supplying HREE, which are relatively rare compared with LREE. We also need to study deposits that may be enriched in HREE, such as alkali rocks and placer deposits. The second challenge is to classify the existence form of REE minerals, and quantitatively evaluate them. Although REE are contained within a variety of minerals, the majority of silicate minerals are difficult to utilize as resources, hence there is a need to explore REE deposits that are suitable for mineral processing and refining, and extractable economically. **GSI and AMD is carrying out REE exploration in the Eastern and Western part of Amba Dongar Carbonatite Complex respectively and strategy for amalgamation of these exploration blocks, identification for gap areas for future exploration etc. will be finalized shortly. Similar exercise will be initiated in other REE prospects and occurrence for joint exploration by GSI &and AMD**.

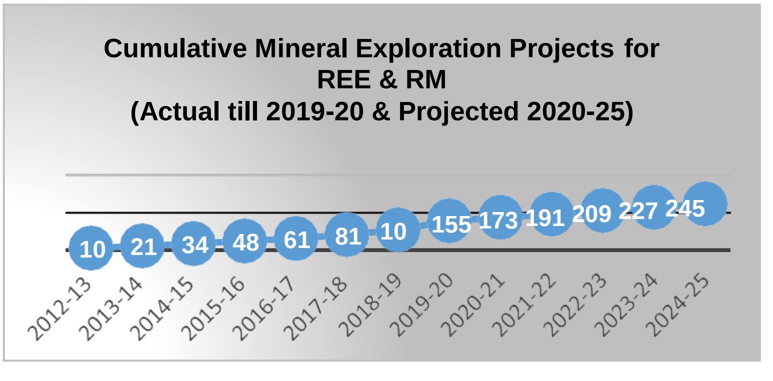
1. Exploration efforts will be focused in various potential geological environments in India. The areas which warrant accelerated exploration efforts include carbonatite, alkaline syenite and pegmatite settings reported from different parts of the country including beneficiation of such ores in Rajasthan, Tamil Nadu, Gujarat and Northeastern States.

2. **Concentration of REE elements will also be studied in the suitable bauxite deposits having a genetic linkage with REE rich primary lithology in the Odisha, Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Madhya Pradesh and Chhattisgarh**.
3. **Regional and semi-regional mineral targeting studies including integrated geological/ geophysical and geochemical surveys for rare metal and REE mineralization in albitite zones especially in Khetri Belt and Singhbhum shear zone will be given a special attention.**
4. The Quaternary sediments to find supergene zones for ion adsorbed REE deposits in the various States will be looked into.
5. The actual exploration projects from the year 2012 to 2017 shows a steady increase in number of projects. There is a quantum rise in the number of mineral exploration projects from the year 2017 to till date by considering the demand for this high technology mineral group all over the world. It has been planned to continue the momentum of mineral exploration for REE in known as well as new geological domains for next five years.
6. Geological provinces in India favorable for REE & RM mineralization which need more intensive search with radiometric data (ground and/ or airborne geophysical) in next five years is as follows:

RM/ REE mineralisation in pegmatites and quartz veins	
	Nellore Mica Belt, Andhra Pradesh. Bihar Mica Belt, Jharkhand. Bhilwara mica belt, Rajasthan. Sausar belt (in skarns) in central India. Tin belt of Odisha and Chhattisgarh.
RM/REE in carbonatite complex	
	Newania carbonatite-fenite complex, Udaipur district of Rajasthan. Ambadongar carbonatite complex, Gujarat. Saidiwasan carbonatite complex, Gujarat. Purulia carbonatite, West Bengal. Sung valley Ultramafic Alkaline carbonatite complex, East Khasi Hills District, Meghalaya. Carbonatite and molybdenum bearing areas in Tamil Nadu. Mundwara alkalic carbonatite complex in Sirohi district, Rajasthan.
RM/REE in igneous complexes	
	Alkaline rocks in Rajasthan. Nepheline syenite of Kishangarh, Ajmer district, Rajasthan. Around Sirohi, Sirohi district, Rajasthan. Granite plutons within Erinpura Granite Terrain. Jalore and Sewaria granitoid terrain in Rajasthan. Chhotnagpur Gneissic Complex in Jharkhand. Bundelkhand Granitoid Complex. Gneisses and granites in the western part of the North Purulia Shear Zone, Jharkhand. Igneous Complexes of Rajasthan, namely, Siwana, Kamthai, Newania.

	Tamil Nadu Igneous Complexes of Sevathur, Pakkanadu, Rasimallai and Samalpatti. Beldih and Kutni along North Singhbhum Shear Zone.
REE enrichment in laterites	
	Jharkhand – Eastern India. Odisha – Eastern India. Laterites developed over Deccan Traps in Gujarat – Western India. Laterites developed directly over Precambrian formations of Western and Central India.
R & D projects of fly ashes, bauxite tailings with the Industry to be taken up	
Urban Recycling R & D projects also be essentially taken as a interactions between Chemists of GSI and other Govt. R & D Labs	
Synergy group on beneficiation studies, R & D projects with IREL, AMD, GSI and IBM needs a serious look.	

7. More emphasis on discovering new REE potential zones by suitable subsurface exploration will be given by taking up Regional Mineral Targeting projects covering the Ambadungar and Saidiwasan carbonatite complexes of Gujarat from next year to delineate the exposed as well as unexposed areas below Deccan basalts by GSI. In the similar way some more projects will be planned in other fertile domains in the country. Systematic drilling investigations in the fertile carbonatite complexes will also be undertaken from subsequent years.
8. AMD/DAE has systematically planned lay out for the exploration strategy for augmentation of REE resources over the period of next five years.
9. **Collective efforts and data sharing especially the airborne electromagnetic, radiometric [subject to approval of MoD and DAE], ground geological, exploratory etc., between AMD and GSI for avoiding the duplicity of work and delineating the new surficial as well as concealed and deep seated REE bodies by application of mineral system concepts. The number of mineral exploration projects with subsurface exploration parameters for REE by GSI is likely to increase in agreement with the receipt of connected data already acquired by AMD.**



Future Research & Development:

- Needs to carryout R & D for identifying the potential zones of REE and its economical extraction as byproduct from phosphorites, coal, lignite etc.
- Working on bioleaching of REE from low concentration ore as R & D project with the suitable academic institution is also expected give new directions.
- Urban mining concept needs to be developed for recycling potential REE bearing electronic and other wastes.

Significant Contributors:

The report has been jointly prepared by GSI and AMD wherein significant contribution has been made by officers of Mineral Exploration divisions of GSI and Director, AMD.

Strategic Plan for
Enhancing REE Exploration in India

GOVERNMENT OF INDIA
GEOLOGICAL SURVEY OF INDIA
MINISTRY OF MINES
&

ATOMIC MINERAL DIRECTORATE FOR EXPLORATION AND RESEARCH
DEPARTMENT OF ATOMIC ENERGY

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