Characteristics and genesis of Rare Earth Element (REE) in western Indonesia

A D Handoko¹ and E Sanjaya²
¹ Mining Technology Assessment, Indonesian Institute of Sciences, Jl Cihaur No. 2 Desa Kertajaya, Sukabumi, Indonesia.
² Geology Engineering Faculty, Padjadjaran University, Jl. Raya Bandung-Sumedang Km.21, Sumedang, Indonesia.
E-mail: aryodwihandoko@gmail.com

Abstract. Rare Earth Element (REE) has unique properties that have been used in many high-tech applications. The demand of REE increased recently in the world due to its special properties. Although REE concentration in the crust is higher than gold, economically viable deposits are still rare. Reduction of REE exports by China cause increased prices of REE. Due to this condition, exploration of potential REE mines emerged. Indonesia also participates in this phenomenon, and explore the possibility of REE mines in its area. This review will discuss the characteristics and genesis of REE and its occurrence in western Indonesia; focused in Sumatera, Tin Island, and Kalimantan. The review is done based on literature research from several resources about characteristics of rare earth element in general and in the given area. The research shows that the potential REE mines can be found in several different locations in Indonesia, such as Tin Island, Sumatera, and Kalimantan. Most of them are composed of monazite, zircon, and xenotime as rare earth minerals. Monazite is known for its elevated number of radioactive elements, so study about radioactive content and more environment friendly ore processing becomes compulsory.

1. Introduction
Rare earth element (REE), as defined by IUPAC, consist of 17 elements. They are 15 lanthanides from lanthanum (La) to lutetium (Lu) with scandium (Sc) and yttrium (Y); more detailed information can be seen at Figure 1 [1]. Many earth scientists exclude scandium from rare earth group because of its distinct properties to other elements [2]. Promethium is also excluded because it is only found as product of nuclear fission [3]. Chakhmouradian suggests that several authors differs in categorizing rare earth into several groups, some of them categorize it into light REE (LREE), heavy REE (HREE) and sometimes mid-REE [4].

Despite its name, rare earth element is not very rare in crustal composition. Although each element has different abundance in the earth crust, the most abundant element (cerium) has concentration more than copper or lead and all other elements—except promethium—more abundant than silver, gold, or platinum [5]. The difference between most and least abundant elements may up to several magnitudes, and in many cases, more than 80% of total REE in REE deposit composed by La, Ce, Pr, Nd [6].

REE was used in many applications in the past and it is becoming more popular in high-tech industry nowadays. REE plays important roles in the high-tech industry that cannot yet be replaced with any other elements, for example: europium as red phosphor in television that does not have any substitute known and several compounds of REE used in small, lightweight, high-strength magnet that does not have any effective substitute yet to be replaced as REE component [6].
China produced most of REE in the world at nearly 97% of REE world supply in 2009 and still dominated the market until 2016 [7][8]. Recent export quota decreased by China is raising other countries awareness of REE importance for their high-tech industries. Previous work suggests that many other countries explore a new source of REE outside China for more diverse supply [4].

Indonesia also joins this trend and search for REE mines prospect in its area. Many research has been done to explore the possibility of REE mining in Indonesia. This research is to review the characteristic and genesis of rare earth element in western Indonesia based on published papers.

![IUPAC Periodic Table of the Elements](image)

**Figure 1.** Rare earth element defined by IUPAC as 15 lanthanides (La-Lu) with scandium (Sc) and yttrium (Y) marked with red box (periodic table modified from IUPAC, 2016).

2. Rare earth mineral

Many currently identified rare earth mineral are distributed in various mineral classes such as halides, carbonates, borates, oxides, hydrates, phosphates, and silicates. Several important REE minerals are bastnasite and monazite with other significant minerals including parisite, synchysite, and xenotime [2].

Lanthanides ionic radius contracted as well as atomic number increases. Effective ionic radii of LREE (La$^{3+}$ – Eu$^{3+}$) are 1.18-1.07 Å and HREE (Y$^{3+}$ with Gd$^{3+}$-Lu$^{3+}$) 1.015 with 1.07-0.97 Å. REE elements frequently substituted by ions that have similar ionic radii such as Na$^{2+}$ (1.16Å), Ca$^{2+}$ (1.12Å), Th$^{4+}$ (1.06Å), and U$^{4+}$ (1.06Å) [9]. Heterovalent exchange between those elements mainly taken place in oxides and silicates [10].

3. Genesis of REE

Rare earth element deposit is rarely discovered in the world. Only several limited mineable deposits are known and most of them are found in China. Rare earth elements usually occur concurrently that if one of REE elements concentration is recognized, other concentration can be estimated by interpolation or extrapolation [4].

REE-bearing deposit can be classified by association of mineralization and host rock. Most of the known mineable REE deposit is hosted in carbonatite, but ion adsorption clay also plays important role in the HREE production [11]. Several authors classified REE deposits in different ways, the detailed classification can be found in Table 1. REE deposit can be classified into three major different
classes in magmatic, structure-related, and sedimentary [12]. Another author also divided REE deposit into three class, igneous, sedimentary, and secondary [10].

**Table 1. REE deposits classification.**

| Dill, H. G.[12] | Kamitani in Kanzawa and Kamitani [10] |
|----------------|--------------------------------------|
| 1. Magmatic rare earth deposits | 1. Igneous |
| 1. REE-P-Nb-Ta-Y-F-(Be-Zr-Th) deposits related to carbonatites | a. Hydrothermal |
| 2. REE-P-Ti deposits related to alkaline igneous complexes | b. Carbonatites |
| 3. REE-U-Nb-bearing pegmatites (in places, transitional into intragranitic deposits with Mo-W-U-Be) | c. Alkaline rocks |
| 4. REE-Nb-P-F-bearing hydrothermal iron deposits | d. Alkaline granites |
| 5. Be- and Y-bearing alkaline intrusive rocks(nepheline syenite) | 2. Sedimentary |
| 3. Structure-related rare earth deposits | a. Placer |
| 1. REE-F-Ba-Th-bearing vein-type deposits | b. Conglomerate |
| 3. Sedimentary rare earth deposits | 3. Secondary |
| 1. REE-(Ti-P-Nb) residual deposits / placers on alkaline igneous and carbonatite complexes | a. Weathered residual of granite (ion-adsorption clays) |
| 2. REE in bauxite | |
| 3. Alluvial- to coastal REE placers | |
| 4. REE-bearing phosphorites | |
| 5. Ion adsorption clay | |
| 6. REE-bearing coals | |

REE may be enriched in magma by fractional crystallization or melt separation. Fractional crystallization can enrich magma by crystallizing lower composition REE mineral and left melt enriched. The concentration of rare earth element may also be derived from partition of homogeneous melt into two or more different melt with distinctive composition, structure, and rheology [13].

Many REE mined from monazite in the past, but nowadays they switched to bastnasite deposit due to environmental impact concerns. Monazite usually has a fair amount of radioactive content that can be released prior to exploitation [6].

**4. Occurrences of REE in western Indonesia**

Several REE deposits found at Tin Island, Sumatera, and Kalimantan with several REE mineral discovered such as monazite, zircon and xenotime in placer deposit with tin or gold deposit, but some of them are also found in pegmatite rocks [14].

Tin Island is part of Tin Belt of Southeast Asia that stretches from Myanmar until Sumatera[15]. REE occurred in placer and granitic rocks. Belitung Island consist of three different type of REE deposits, secondary type deposit with xenotime, monazite, and alluvial zircon as accessory mineral to alluvial tin mining, residual type ore deposit of ion-adsorption type in kaolin formed from weathering of Tanjung pandan granite, and rare type of deposit with association with magnetite-hematite (Thorib et al. in Soepriadi et al. [16]). Neutron Activation Analysis on Klabat granitic rocks shows cerium concentration at lowest 3.3 ppm and highest 383.0 ppm with average concentration 100-200 ppm [17].
Research also found that abundant concentration of REE at tin tailing concentrate and tailing in Tin Island [18].

Research in Western Kalimantan shows that it also hosts REE mineral occurrence of monazite [19]. The research result also shows that granitic rocks that host tin deposit in Tin Island play an important role in zircon sand that occurred concurrently with gold placer which contain REE mineral in Western Kalimantan.

One of REE occurrence in North Sumatera, located in Pegunungan Tigapuluh - North Sumatera, has been researched [20]. It shows quartz stock-work with pegmatite and leucocratic granite in Isahan and Sikambu River. The host rock contains cerium. Chemical analysis shows that pegmatite has 0.08-0.24% cerium. Pegmatite in Sikambu River shows similar mineralization with pegmatite in Isahan with 372 ppm cerium and 26 ppm yttrium. Chemical analysis in Parmonangan also shows a significant amount of cerium, between 113-275 ppm.

5. Conclusions
The research shows that rare earth element can be found in many parts of Indonesia, namely Tin Island, Sumatera, and Kalimantan; occurred in both placer and granitic rocks. Most of the rare earth mineral found there are monazite, xenotime, and zircon. A study of radioactive elements should also be taken to assess the environmental impact of potential REE mine because monazite usually has a fair amount of radioactive content. Furthermore, research about more environmental ore mineral processing must be conducted to minimize radioactive pollution.

Rare earth element found in several different deposit forms; secondary deposit and primary deposit. Secondary deposit that occurred in the given area in ion-absorption clay and placer deposit form derived from weathering of primary deposit. In addition, primary deposit is discovered in the area in the form of pegmatite and granitic rocks.

Acknowledgments
We thank the anonymous reviewers as well as a lot of valuable suggestions from our friends and colleagues for giving us much valuable and important information related to our research topic. Many thanks also contributed to other people that we cannot describe in this opportunity so we can publish our work.

References
[1] Connely N G, Hartshorn R M, Damhus T and Hutton A T 2005 Nomenclature of inorganic chemistry IUPAC Recommendations 2005 IUPAC Periodic Table of the Elements Fm No
[2] Henderson P, Gluyas J, Gunn G, Wall F and Woolley A 2011 Rare Earth Elements 13
[3] Bounds C O 1998 The Rare Earths : Enablers of Modern Living PROCESSING OF RARE J. Miner. Met. Mater. Soc. 50 38–42
[4] Chakhmouradian A R and Wall F 2012 Rare earth elements: Minerals, mines, magnets (and more) Elements 8 333–40
[5] Gosen B S Van, Verplanck P L, Long K R, Gambogi J and Seal II R R 2004 The Rare-Earth Elements — Vital to Modern Technologies and Lifestyles 1–4
[6] Haxel G B, Hedrick J B and Orris G J 2002 Rare Earth Elements — Critical Resources for High Technology
[7] Anon 2010 Mineral Commodity Summaries 2010 : U.S. Geological Survey
[8] Anon 2017 Mineral Commodities Summaries 2017 (U.S. Geological Survey)
[9] Shannon R D and Prewitt C T 1969 Effective Ionic Radii in Oxides and Fluorides Acta Crystallogr. Sect. B 25 925–46
[10] Kanazawa Y and Kamitani M 2006 Rare earth minerals and resources in the world J. Alloys Compd. 408–412 1339–43
[11] Simandl G J 2014 Geology and market-dependent significance of rare earth element resources Miner. Depos. 49 889–904
[12] Dill H G 2010 Earth-Science Reviews The “chessboard” classification scheme of mineral deposits: Mineralogy and geology from aluminum to zirconium Earth Sci. Rev. 100 1–420
[13] Chakhmouradian A R and Zaitsev A N 2012 Rare earth mineralization in igneous rocks: Sources and processes Elements 8 347–53
[14] Tampubolon A, Pardiarto B, Gunradi R and Sulaeman 2015 Unsur Tanah Jarang di Indonesia: Geologi, Eksplorasi dan Pengembangannya (Bandung: Pusat Sumber Daya Geologi - Badan Geologi)
[15] Johari S and Umi K 1991 The Occurences of Rare Earth Minerals in Indonesia Rare Earth Minerals and Minerals for Electronic Uses Materials Science Forum vol 70(Trans Tech Publications) pp 640–5
[16] Soepardi, Budiharyanto K and Widi B N 2014 Prospeksi Unsur Tanah Jarang (Rare Earth Elements) daerah Kacang Butor dan Sekitarnya, Kecamatan Badau, Kabupaten Belitung Provinsi Bangka Belitung (Bandung) pp 1–16
[17] Widana K S, Priadi B and Handayani Y T 2014 Profil Unsur Tanah Jarang Granitoid Klabat di Pulau Bangka dengan Analisis Aktivasi Neutron Eksplorium 35 1–12
[18] Irzon R, Sendjadja P and Soebandrio J 2014 KANDUNGAN RARE EARTH ELEMENTS DALAM TAILING TAMBANG TIMAH J. Geol. dan Sumberd. Miner. 15 143–51
[19] Muliyana T and Putra E 2015 Penyelidikan dan evaluasi potensi rare earth element (REE) dan mineral ikutan pada wilayah bekas tambang/tailing di Kecamatan Kendawangan, Kabupaten Ketapang, Provinsi Kalimantan Barat (Pusat Sumber Daya Geologi - Badan Geologi)
[20] Suwargi E, Pardiarto B and Ishlah T 2010 Potensi Logam Tanah Jarang di Indonesia Bul. Sumber Daya Geol. 5 131–40