Rare Earth Element Exploration in Indonesia

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ABSTRACT

Rare earth elements exploration in Indonesia have began to grow for last few years was affected by restrictions on exports of rare earth metals from China to meet their own needs. Various countries becomes the object of the research potential of REE including Indonesia. Some region in Indonesia showed potential resources of rare earth LTJ, especially in Bangka Belitung, Kalimantan and West Sulawesi. BATAN has conducted research of rare earth elements from exploration through to processing of separation REE from radioactive elements. Besides associated with radioactive minerals, REE contained in insitu washing up to smelter from the tailing and rest of the tin mining. Thorium are compatible elements with REE, comparison of Th and REE content in soil/rock are linear. Monazite and thorianite both are radioactive minerals contain REE found in two prospect region in Bangka Belitung Island and Mamuju–West Sulawesi, respectively.

Keywords: Rare Earth Elements, Exploration, Bangka Belitung, Mamuju

INTRODUCTION

Rare earth elements (REE) are group of 17 chemically similar metallic elements, including the 15 lanthanides, scandium, and yttrium. The term rare earth is a misnomer arising from the rarity of the minerals from which they were originally isolated (Rudnick et al. in Walter et al., 2011). The rare-earth elements are often informally subdivided into “heavy rare earths” and “light rare earths” based on the atomic number of the element (Figure 1). Lanthanum, cerium, praseodymium, neodymium, promethium and samarium, with atomic numbers 57 through 62, are generally referred to as the “light rare earths.” Yttrium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium, with atomic numbers 39 and 63 through 71, are generally considered the “heavy rare earths (Szumigala and Werdon, 2011).

REE usage in glass polishing and ceramics are the largest market for REE commodities by weight (Figure 2). Substantial amounts of cerium concentrates and cerium oxide are used in glass-polishing applications. The automotive catalyst industry also consumes significant REEs by weight, using cerium carbonate and cerium oxide in the catalyst substrate and as a component of the converter’s oxidizing catalyst system. The use of lanthanum-rich mixed REE compounds in fluid cracking catalysts (FCCs) in petroleum refining also has been a major market. Phosphors, electronics, and laser crystals provide relatively minor markets by weight, although most are high value. The future use of REEs is expected to increase, especially in automotive pollution catalysts, FCCs, and permanent magnets. Rare earth applications are expected to need greater amounts of higher purity mixed and separated products, requiring specificity in their unique properties. Strong demand for cerium, lanthanum, and neodymium is expected to continue throughout the decade as automotive and electronic usage expands with population growth. Future growth also is forecast for REEs used in lasers, fiber optics, and medical applications that include MRI contrast agents, PET scintillation detectors, medical isotopes, and dental and surgical lasers. On the other hand, demand is expected to decline over the next decade for REE phosphors used in CRTs, as

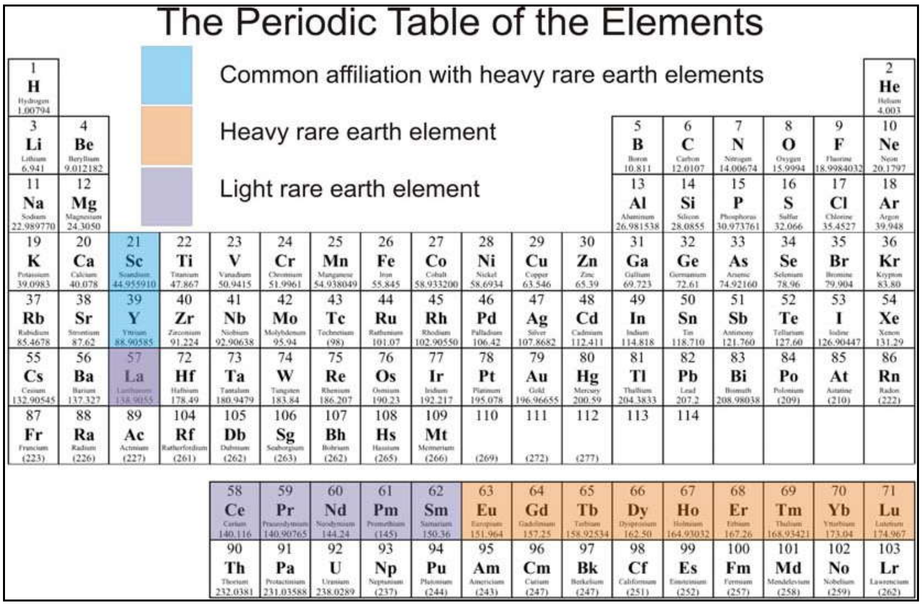

Figure 1. Periodic table of the elements with rare-earth elements highlighted (Szumigala and Werdon, 2011)

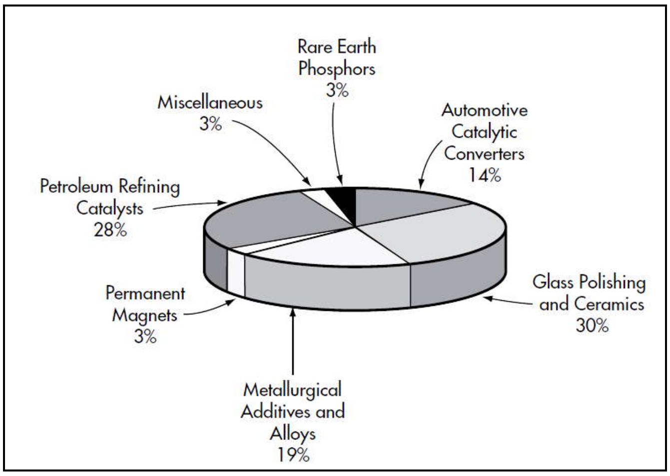

Figure 2. Rare earth markets by weight (Castor and Hedrick, 2006)

flat-panel display use increases. A slight decline also is forecast for rechargeable nickel-hydride batteries, as lithium ion batteries gain wider use in portable electronics. Long-term growth is forecast for REEs utilized in magnetic refrigeration alloys and other technologies that exhibit energy efficiency and cost benefits (Castor and Hedrick, 2006).

Global production trends of REE from 1950 to 2010 recognized four major global production periods, namely: a monazite-placer period starting in the late 1800s through to the mid-1960s; the Mountain Pass (USA) period commencing in 1965 and ending around 1984; a transitional period of mixed contributions from China, USA, and other countries from1984 to 1991; and the Bayan Obo (China) period starting in 1991 and which continues to increase production to the present day (Figure 3) (Jaireth et al., 2014).

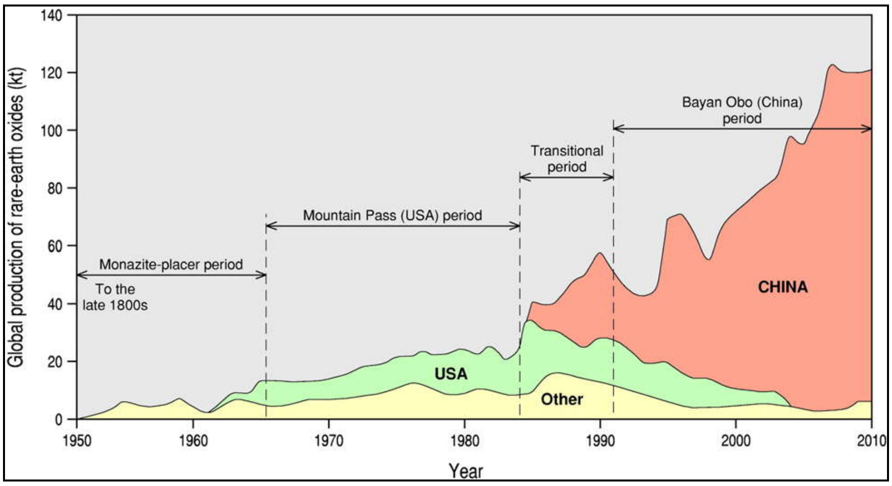

Figure 3. Global production of rare-earth oxides, 1950 to 2010. The relative minor production contribution from other countries is largely from monazite-bearing placers (Jaireth et al, 2014)

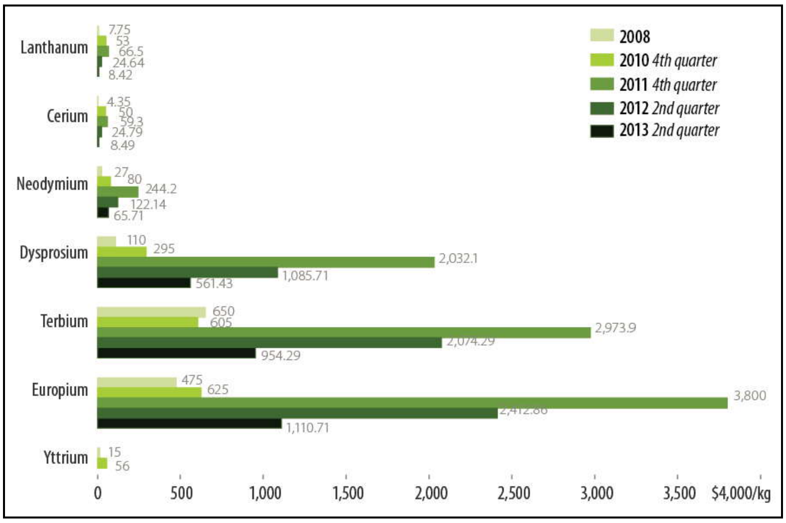

Figure 4. Selected Rare Earth Oxide Prices, 2008-2013 (US $/kg) (Humpries, 2013)

Prices of rare earth oxides and metals rose rapidly in 2010 and 2011 but declined in the first half of 2012 and declined further by the 2nd quarter in 2013. Most rare earth experts would agree that the most recent restrictions on Chinese exports and lack of capacity elsewhere led to the sharp price rise and while price declines resulted from of softer demand (e.g., some substitution, high stocks, and a slow economic recovery). Figure 4 illustrates recent price increases and declines of selected rare earth oxides. With a potential for a surge in demand and continued export restrictions it may take time for global supply of the heavy rare earth elements to catch up. Prices for the HREEs may remain high in the short-term but, typically, tend to fall back to the industry's marginal cost of production after supply increases (Humpries, 2013).

Rare earth elements (REE) are, contrary to the name, relatively abundant in the earth's crust. This group of 17 metals is commonly divided into light REE (LREE) and heavy REE (HREE). The LREE cerium is nearly as abundant as copper. Lanthanum and neodymium are quite common as well. HREE such as dysprosium and terbium are less common, but even the rare stones occur more often than gold and silver. Only natural promethium does not exist on the earth (Webelements, 2011). According to Walter et al. (2011), REEs are relatively plentiful in the earth's crust having an overall crustal abundance of 9.2 ppm. Nevertheless, although rare earth elements are relatively abundant in the Earth's crust, they are rarely concentrated into mineable ore deposits (Long et al, 2010).

REE do not occur naturally as metallic elements. REE occur in wide range of mineral type includes halides, carbonates, oxides, phospates and silicates. The REE are largely hosted by rock-forming minerals where they substitute for major ions. The vast majority of resources are associated with just three minerals, bastnasite, monazite and xenotime. Bastnasite and monazite are the primary source of the LREE, mainly Ce, La, and Nd. Monazite has a different balance as it contains less La and more Nd and HREE (NERC-BGS, 2011).

REE mineral deposits occur in a broad range of igneous, sedimentary, and metamorphic rocks. The concentration and distribution of REE in mineral deposits is influenced by rock forming and hydrothermal processes including enrichment in magmatic or hydrothermal fluid, separation into mineral phases and precipitation, and subsequent redistribution and concentration through weathering and other surface processes. Environment in which REE are enriched can be broadly divided into two categories: primary deposits associated with igneous and hydrothermal processes, and secondary deposits concentrated by sedimentary processes and weathering. The primary deposits, further divided into carbonatite associated, alkaline igneous rock associated, iron-REE deposits, and hydrothermal deposits (unrelated to alkaline igneous rocks). The secondary deposits divided into marine placers, alluvial placers, paleoplacers, lateritic deposits, and ion-adsorption clays (NERC-BGS, 2011).

Grade of Re_2O_3 from world most important deposit, Bayan Obo and Mountain Pass are shown in Table 1. Major oxide chemistries of several Bayan Obo ore types mainly is bastnasite and monazite, but at least 20 other REE-bearing minerals have been identified. The grade of Re2O3 are in the range of 2.73 to 42.75%. Mountain Pass ore grades which is mostly bastnasite are in the range of 9.89 to 13.18%.

Because REEs are associated with thorium and uranium, radiometric exploration techniques are extremely useful in REE exploration. REE-rich carbonatite at Mountain Pass was discovered during surface prospecting for uranium using a geiger counter (Olson et al. 1954 in Castor and Hedrick, 2006). Many other REE deposits were found by surface or airborne radiometric surveying. Although most placer REE deposits yield only subtle radiometric signatures, careful data collection and analysis can be used to locate favorable intrabasin areas or horizons. Almost all of the45 important source of minerals for rare earth are contained uranium or thorium, which is bastnasite, monazite, and xenotime (Table 2).

METHODOLOGY

National Nuclear Energy Agency (BATAN) with with competence radioactive mineral exploration, primarily investigating potential occurrences of uranium and thorium are often associated with rare earth elements. Thus, in the exploration also known the potential of rare earth elements.

Methodology applied in this research is radiometric K, U, and Th mapping, geochemical heavy mineral sampling on mineral sand, laboratory XRF analysis of the concentrate or whole rock, and data presentation and analysis. Some REE deposit types are selected in Sunda Land or its surrounding named placer/paleoplacer deposit of Bangka-Belitung and Ketapang, metamorphic deposit of Rirang in West Kalimantan, and lateritic and alkaline igneous rock deposit of Mamuju.

Table 1. Major oxide chemistry of ore samples from Bayan Obo and Mountain Pass (Castor and Hedrick, 2006)

	Bayan Obo*									Mountain Pass†	
Samples	**Mfe**	**Ffe**	**AeFe**	**RiFe**	**MDT**	**7B30-20**	**7B30-45A**	**7B30-28B**	**7B31-10**	**85-4**	**R-724**
SiO_2	4.81	2.18	23.86	10.79	8.74	na‡	na	na	na	0.40	1.63
TiO_2	0.27	0.62	0.56	0.55	0.28	1.00	0.15	0.23	0.08	0.01	0.01
Al_2O_3	0.22	0.66	1.55	0.83	0.74	0.06	0.25	0.17	0.26	0.01	0.01
Fe_2O_3§	74.73	39.29	31.61	44.59	11.69	7.72	13.87	37.17	5.00	0.24	1.77
MnO	0.79	0.12	0.07	5.95	1.18	0.01	0.03	0.02	0.01	0.24	0.45
MgO	0.99	0.31	0.30	3.52	13.23	<0.03	0.07	0.25	0.12	0.04	6.41
CaO	8.78	26.26	11.59	16.15	27.09	27.98	27.98	3.92	8.67	21.30	11.73
SrO	0.36	3.90	5.67	1.15	0.25	0.05	0.10	0.07	0.09	14.15	2.49
BaO	na	na	na	na	na	0.04	3.80	2.79	2.46	14.63	25.12
Na_2O	0.25	0.25	4.06	0.62	0.12	na	na	na	na	0.05	0.07
K_2O	0.09	0.08	0.57	0.92	0.58	<0.24	<0.24	<0.24	<0.24	0.05	0.09
P_2O_5	0.94	2.71	2.85	1.16	1.47	na	na	na	na	0.04	0.29
F	5.89	16.83	7.25	8.31	1.83	17.00	14.4	1.68	4.49	0.70	1.40
CO_2	na	na	na	na	na	na	na	na	na	19.84	18.26
SO_3	na	na	na	na	na	na	na	na	na	18.26	15.43
LOI	2.89	5.15	5.62	5.60	25.23	na	na	na	na	na	na
RE_2O_3	2.73	9.49	7.72	3.24	3.98	19.32	8.67	10.89	42.75	9.89	13.18
Nb_2O_5	na	na	na	na	na	0.36	0.02	0.05	0.53	0.001	0.004
Total	103.74	107.85	103.28	103.38	96.41	73.54	69.34	57.24	64.46	99.85	98.34

Source: Yuan et al 1992; Chao et al. 1997; Castor and Nason 2004.
* Bayan Obo:
Mfe = massive REE-Fe ore
Ffe = fluorite REE-Fe ore
AeFe = aegerine REE-Fe ore
RiFe = riebeckite REE-Fe ore
MDT = magnetite-dolomite ore
7B30-20 = high-REE, low-FE banded ore
7B30-45A = bastnasite-apatite-pyroxene-fluorite ore
7B30-28B = high-Fe, REEs, and fluorite ore
7B31-10 = high-REE, low-Fe, and low-F ore
† Mountain Pass:
85-4 = bastnasite-barite sovite, Sulphide Queen ore body
R-724 = bastnasite-barite beforsite, Sulphide Queen ore body.
‡ na = not available.
§ All Fe as Fe_2O_3.

Table 2. Rare earth elements, thorium, and uranium content of minerals found in rare earth elements deposits (Long et al., 2010)

Mineral	Formula	Content (weight percent)		
		REO	ThO_2	UO_2
Bastnasite (Ce)	*$(Ce,La)(CO_3)F$*	*70 to 74*	*0 to 0.3*	*0.09*
Brannerite	*$(U,Ca,Y,Ce)(Ti,Fe)_2O_6$*	-	-	-
Loparite (Ce)	*$(Ce,Na,Ca)(Ti,Nb)O_3$*	*32 to 34*	-	-
Monazite (Ce)	*$(Ce,La,Nd,Th)PO_4$*	*35 to 71*	*0 to 20*	*0 to 16*
Xenotime (Y)	*YPO4*	*52 to 67*	-	*0 to 5*
Thorite	$(Th,U)SiO_4$	≤3	-	10 to 16
Zircon	$(Zr,REE)SiO_4$	-	0.1 to 0.8	-
Uraninite	$(U,Th,Ce)O_2$	-	-	-

italic=historically have been processed

RESULT AND DISCUSSION

Bangka Belitung province has long been known for its tin mining. Tin from Bangka Belitung is produced from primary and secondary deposit. Some veins in granite rock has high grade of tin, but its occurrences are limited compared to secondary deposit which is alluvial and beach placer. Rare earth element in Bangka-Belitung expected to result from monazite, zircon, and xenotime. Geological map of Bangka-Belitung shows the source of monazite, zircon and xenotime which is granite with the age of Triassic to Cretaceous. Several alluvial environment which has the granitic rock in the upstream part are contain rare earth minerals. Geological map of Bangka-Belitung province are has been described by Mangga et al. (1994), Margono et al. (1995), and Baharudin et al. (1995), the area is covered mostly by paleozoic metasediment, triassic sandstone, and triassic to cretaceous granite, and recent alluvial.

Radiometric map of Bangka Island has been established in the year of 2013. The radiometric map shows content of K, U, and Th in rock and soil. The expected goal is it can be indicator of the area with high REE minerals, nevertheless the alluvial deposits areas are hidden by high radiometric of granite (Figure 5). Beside that, the horizon of heavy minerals are located in deeper portion of alluvial, and its covered by soil and fine grained materials. The fluvial bottom placers overlying the Paleozoic-Mesozoic bedrock are called kaksa by Indonesian miners.

Beside the natural REE deposit environment of placer and vein, the more interesting material stock for REE bearing minerals comes from by-product of tin washing plant in the form of monazite or xenotime concentrate, or in the form of Slag-2 which is waste of tin smelter. In the mining process of tin, the tailing of mining and washing process still contain REE minerals. The product of the mining process is tin and zircon sand. Move forward, the processing plant to produce concentrate are also has by-product of monazite, ilmenite and zircon. Generally, REE contain from intermediate washing process and concentrate are up to 17 % and 70 %, respectively. The smelting process of tin concentrate are also valuable for REE. The smelting process generally divided into two processes, which is stage 1 and stage 2. On the stage 1 of smelting, tin block and slag-1 resulted, the slag-1 then re-processes in smelter to result tin block and slag-2. Slag-2 is considered as waste by smelter company while its still contain 7 – 10% of REE, 1% of U, and up to 1,5 % of Th.

In Ketapang, West Kalimantan river catchment area of Pesaguan and Kendawangan is location of the placer deposits of REE bearing minerals. The sources rock will be upper cretaceous granite of the Schwaner complex. Based on radiometric dating using K-Ar for granitic rock in Ketapang which is Belaban granite and Sukadana granite, it is concluded that the age of Belaban granite is 157±3.5 Ma, and Sukadana granite is 80.7±3.3 Ma – 130.2±2.8 Ma (Witts, 2012), other research shows that the age of Sukadana granite is 79 – 127 Ma which is based on K-Ar dating of hornblende and biotite (Hattum, 2013) (Figure 6).

To build a model of monazite deposit, a research is conducted in Rangkung, Kendawangan, Ketapangan-West Kalimantan. Research conducted by radiometric mapping, geological mapping, geochemical heavy mineral sampling, and laboratory minerals grains counting. The result of radiometric mapping shows high radiometric anomalies in placer deposit near or in the area of granitic rock (Figure 7). Counting on monazite grains in heavy minerals samples shows that the monazite could be present in the range of 2 to 8% (Figure 8). Dominant heavy minerals grains present in the recent alluvial is Zircon with the range between 14 to 45% (Figure 9). Besides in-situ resources, rare earth and thorium bearing minerals, which is zircon, also identified in several zircon traditional mining in Kendawangan, West Kalimantan. To represent the actual mining process, sample for laboratory analysis are taken from the result of traditional miners. Samples then analysed for its Re2O3 content, and resulted the grade

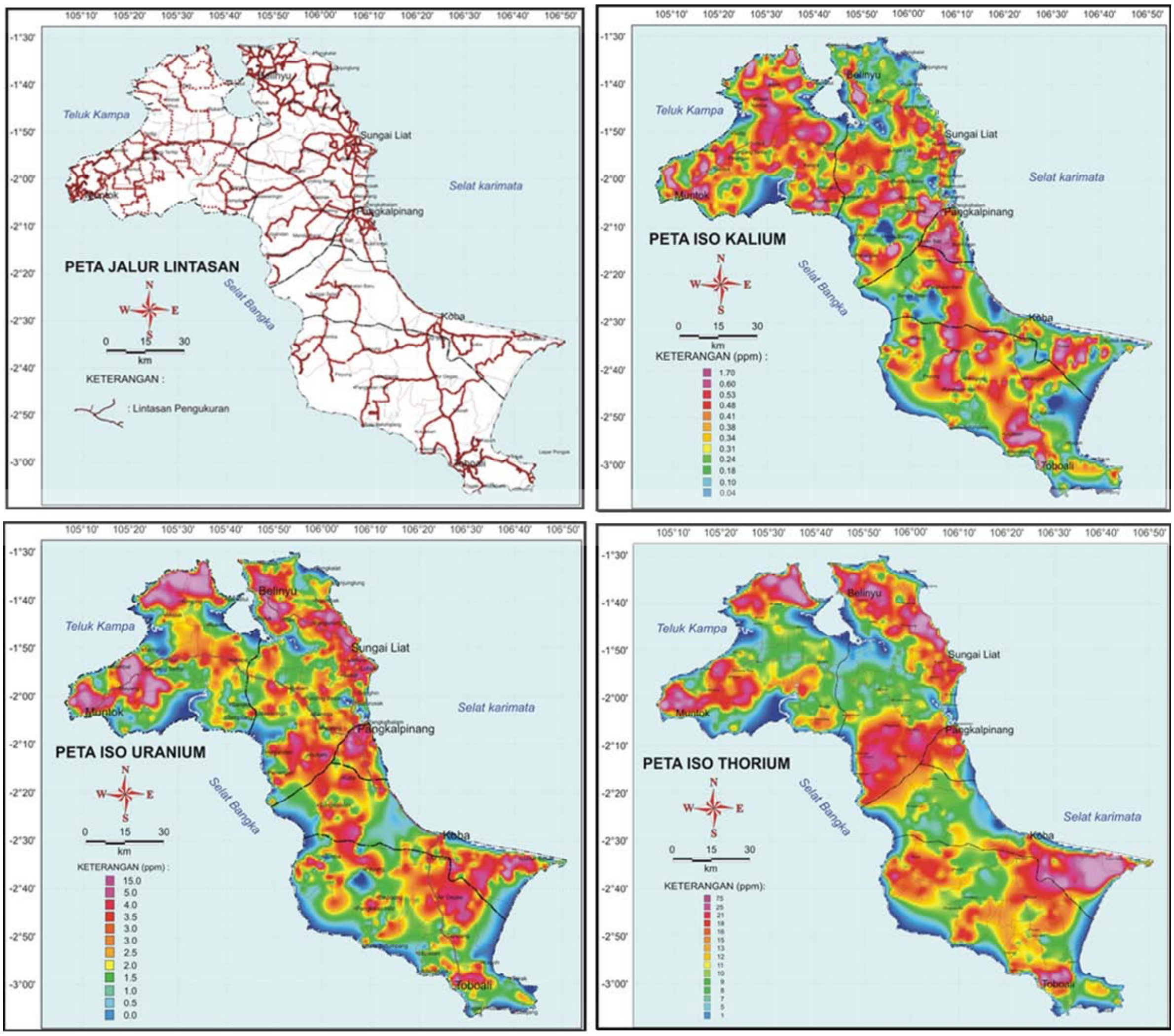

Figure 5. Radiometric map of K, U, and Th

of Re2O3 varies between 0,15 to 0,25%.

East from Ketapang area, in the border of West Kalimantan and Central Kalimantan province, the area of interesting REE deposits, which is Rirang River Valley lay in Kalan Basin. Kalan Basin is sedimentary basin contain siltstone, pelite and claystone, with sandstone interbedded, and all has been metamorphosed. The metamorphism is lowgrade Abukuma regional at the condition around 540^{o}C of temperature and 2000 bar of pressure (Tjokrokardono and Soetarno, 2004). The Kalan Basin now is a big masses on the roof of tonalite.

Rirang has been well known because its rich mineralized boulder. Several boulder with centimetric, desimetric, to metric have been discovered along 1000 m of the Rirang river bed. Most of boulders are banded blocks (monazite type) and some are non-banded blocks (tourmaline type). Monazite type are composed of dark centimetric fragments of breccia, roughly aligned, giving a banded aspect, and are cemented by lighter colour monazite. The mineral composition of the dark bands is fine grained brown monazite, molybdenite, ilmenite, rutile, and tourmaline.

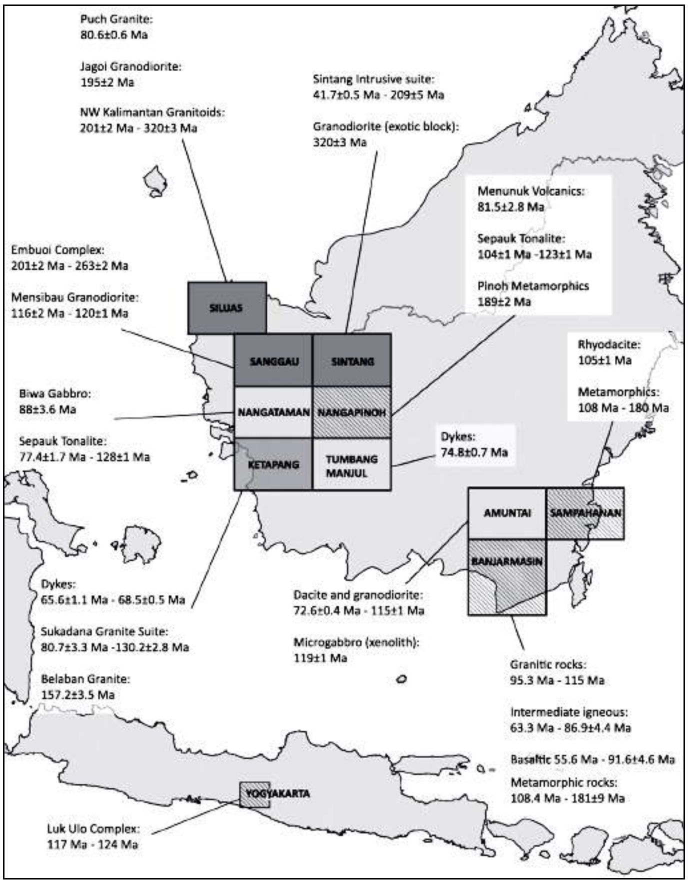

Figure 6. Granitic rock and its age as source for REE bearing minerals (Witts, 2012)

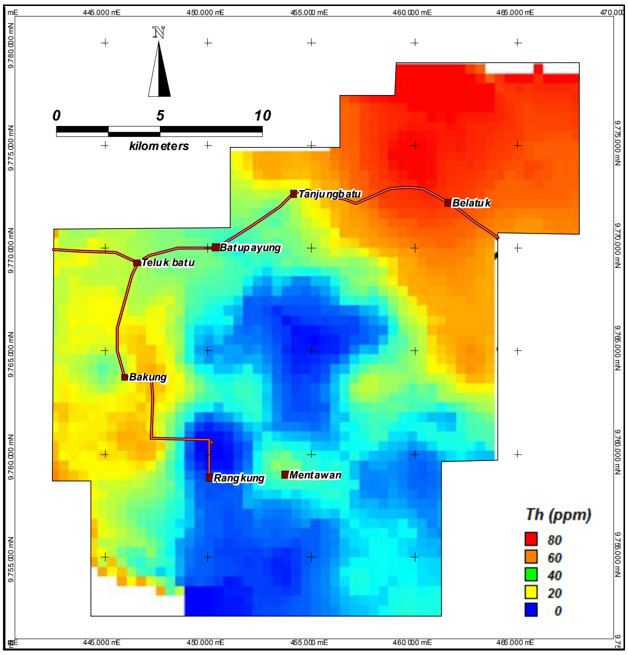

Figure 7. Radiometric map of thorium in Rangkung, Kendawangan

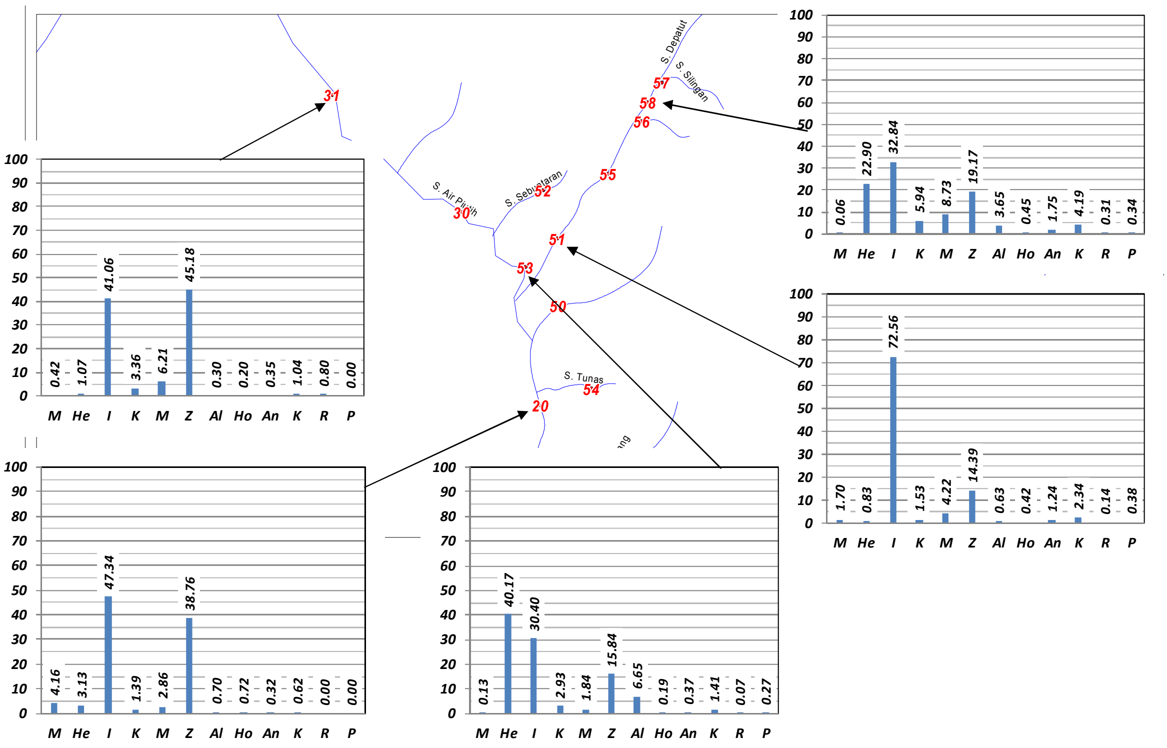

Figure 8. Monazite occurrences in Airputih River, West Kalimantan

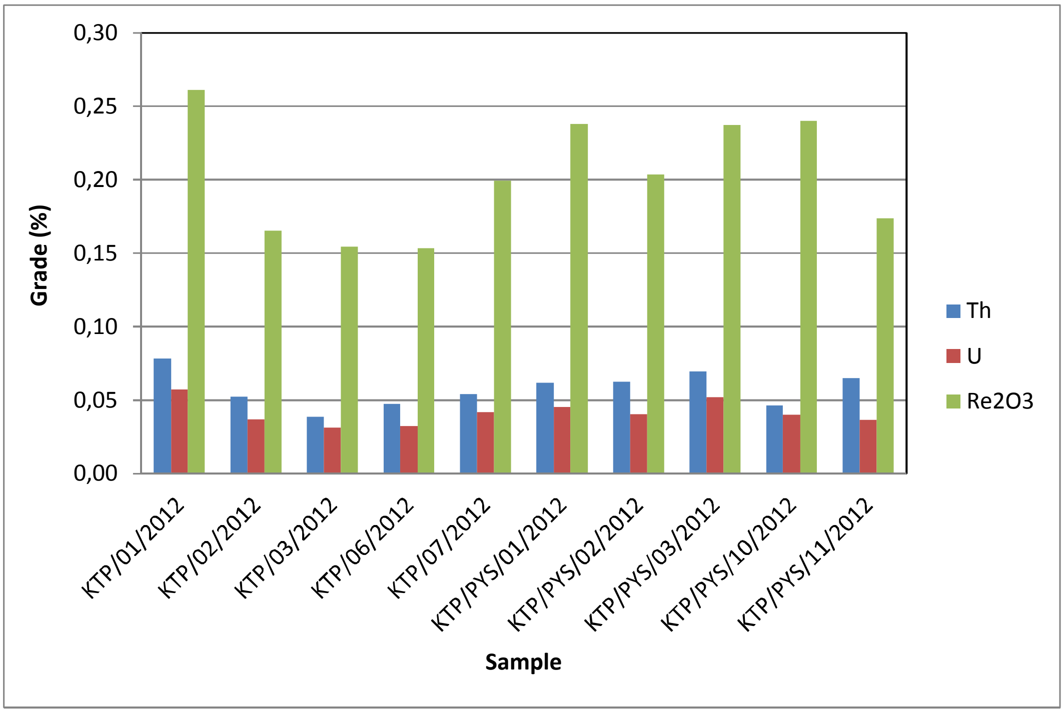

Figure 9. Rare earth element in zircon sample

Table 3. Modified chemical analysis of Rirang Boulder (wt%) (Tjokrokardono, 1985)

Oxides/Element	Monazite type		Tourmaline type	
	Sample a	Sample b	Sample c	Sample d
SiO2	3.25	11.5	44.36	59.03
Al2O3	2.25	2.27	16.82	19.61
Fe total	0.9	1.02	5.48	2.41
CaO	1.85	0.46	4.29	1.82
MgO	0.2	-	0.55	0.57
P2O5	23.5	44.0	15.15	5.72
Re2O3	59	35.78	0.045	0.332
Ti2O3	1.33	0.69	0.64	0.69

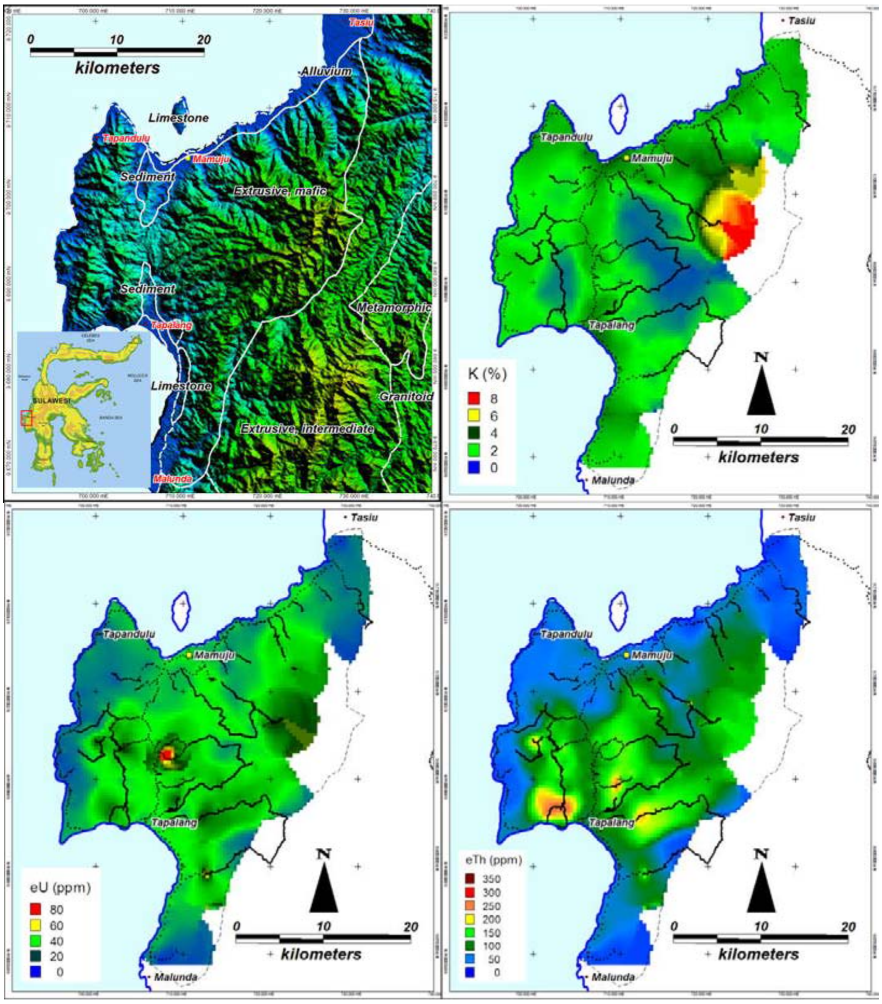

Figure 10. Radiometric Map of Adang Volcanic Formation (Syaeful et al., 2014)

Mineralization of monazite boulders is hosted in ganggue which almost entirely made of monazite. The chemical analysis of the boulder indicates high rare earth element which is up to 59%, high phosphate contents, low alumina and silica content in monazite type (Table 3). The non-banded type also has low rare earth element, however its relatively high in silica, alumina, and iron content (Tjokrokardono, 1985). Based on the research conducted by Suharji and Widodo (2001) total of resources in Rirang Sector are 71,37 tons U_3O_8 and 2.385,84 tons REE. Research conducted by geological and topographical mapping, trenching, channel sampling, chemical analysis, petrography, and autoradiography.

In Mamuju, West-Sulawesi, the REE bearing minerals found in volcanic rocks of Adang Formation. Adang Formation composed by extrusive volcanic product, which is a mafic rock of leucite basaltic tuff, lava and volcanic breccias (Ratman and Atmawinata, 1993). It is cover large area with up to 800 km^2. In detailed field geological mapping it is found that the Adang Volcanic formation composed by feldsphatoid lava rock, pyroclastic, tuffities, and sandstone. In term of radiometric, the area has generally higher radiation dose rate than its surrounding area. Talaya Formation which is bordered the Adang Formation has a significantly lower dose rate. In the southern boundary of the geological formation in the area of the Taan village, the radiation dose rate drops from approximately 400 nSv/h in Adang Volcanic to 100 nSv/h in Talaya Volcanic. In the northern boundary, the dose rate decreases slightly from approximately 250 to 200 nSv/h (Syaeful et al., 2014). Radiometric map of potassium shows high anomaly in the center of volcanic, which is the central crater of the volcanic with the grade from 6 to 8%, from uranium radiometric map the high anomaly located in Botteng, which is secondary uranium leached in volcano sedimentary deposit. Radiometric map of thorium shown more likely the area of REE occurrences (Figure 10). The anomaly areas located in structural controlled vein and supergene enrichment type of deposit.

More than 70 samples from field survey has been analyzed for its contained rare earth element. The most interesting samples, the MJU-19 to MJU-21 are contain high Ce, La, and Nd which is LREE (Figure 11). The samples are taken from upstream part of Mamuju river, in the crater area of Adang Volcanic Formation. From the sample analyzed, comparison of Th and REE content in soil/rock are almost linear, which can be concluded that the radioactive mineral species would be dominated by Th. Grade of Re2O3 in soil/rock achieve almost 1.2% (Figure 12). On further analysis of radioactive mineral by scanning electron microscope, the type of radioactive mineral is thorianite. REE deposits in the world which is containing thorianite found in Roy Creek, Mount Prindle area, Alaska (Armbrustmacher, 1989).

CONCLUSION

REE bearing mineral in Indonesia found in placer deposits of tin and zircon, metamorphic deposits of Rirang boulder, and volcanic deposit of Mamuju. In term of grade the metamorphic deposit of Rirang boulder has very significant value of REE contained which can be up to 59%. The problem rose with low available resources along with the question mark on genetic emplacement of the boulder. Monazite concentrate as by-product of tin mining has higher in resources but highly dependable to tin mining, and not feasible to mine as single commodity. The Mamuju volcanic deposit up to now still undergo the preliminary exploration for its radioactive minerals and REE contained. The complexity of mineralization is highly challenging for further exploration and/or development of the area. Main problems comes when all of deposits are considered radioactive, which is less advantageous compared to bastnasite REE mineral in China. Government involvement in term of processing research incentive, radioactive material management and storage is desired to assist the industry in competition with current world market and production.

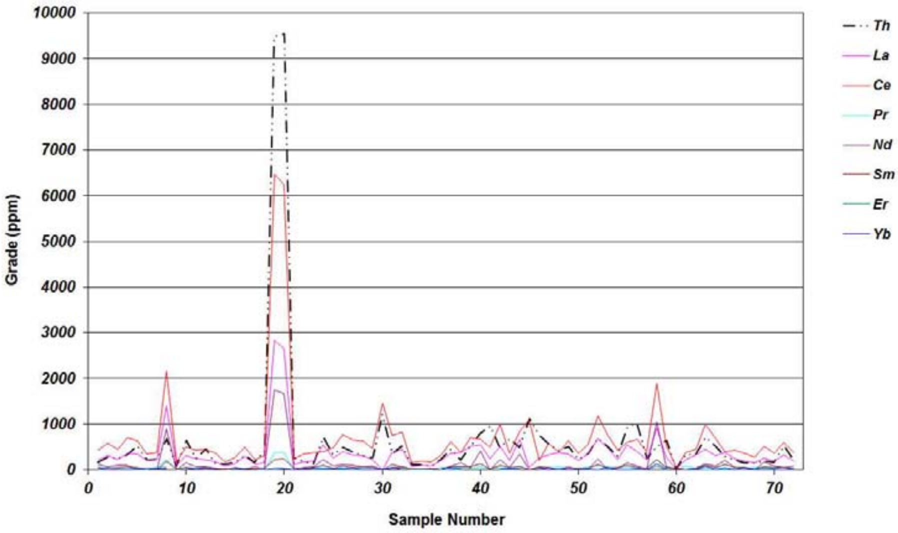

Figure 11. REE in samples

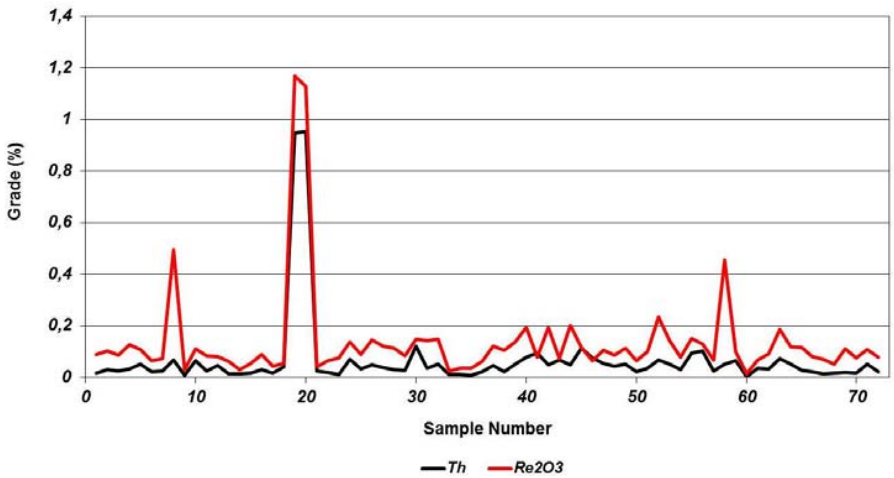

Figure 12. Grade and comparison of the Th and Re2O3 in samples

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