با سلام

Good Afternoon

An Introduction to the

Critical Minerals (CMs)

By

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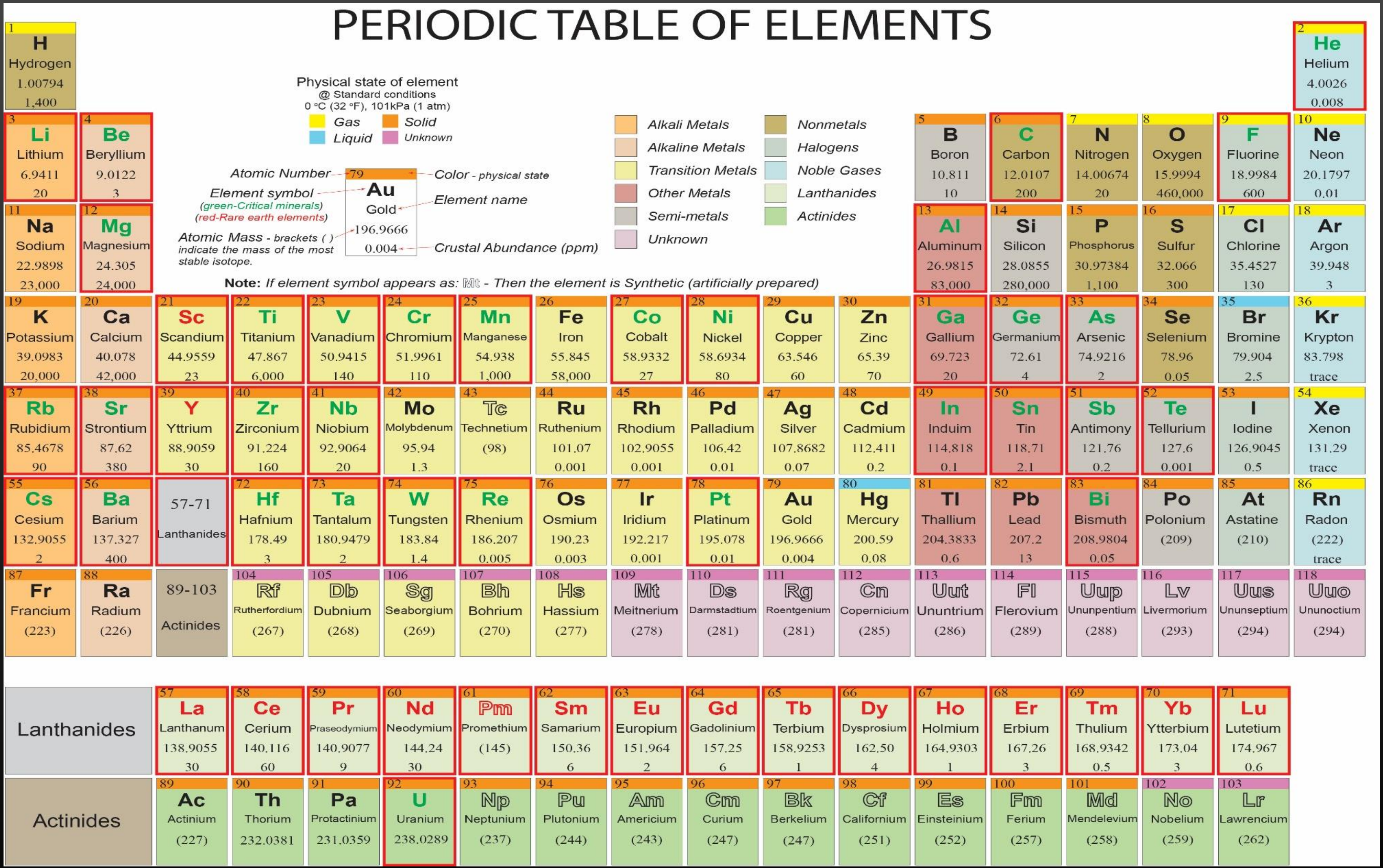
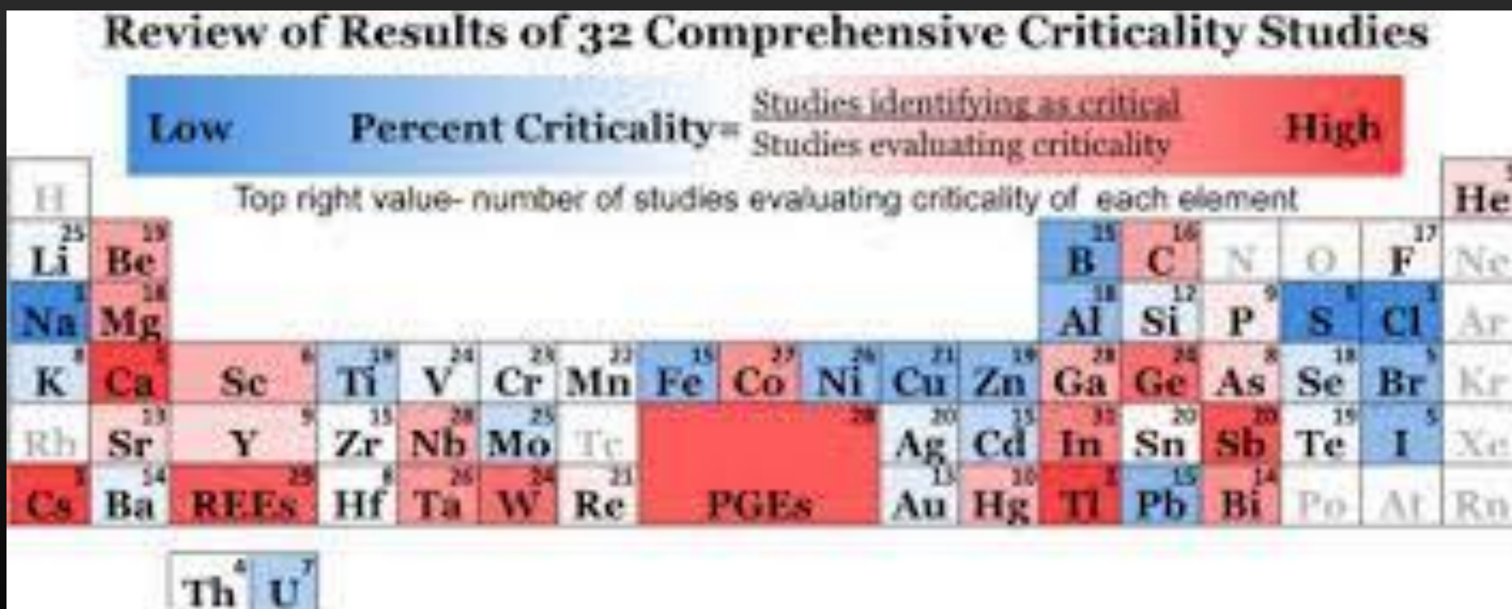
Content

1. Introduction



What are the Critical Minerals/Elements?

1. CMs/Es are those that are essential **to the economy**.
2. Supply may be disrupted.
3. They tend to be those on which a country is heavily import-reliant.
4. They will vary from country to country.
5. Demand for many of these minerals has skyrocketed in recent years with the spread of high-tech devices that use a wide variety of materials.



6. The 'criticality' of a mineral changes with time as supply and society's needs shift. *Table salt, for example, was once a critical mineral. Today, many critical minerals are metals that are central to high-tech sectors.*

7. They can be metals and non-metals whose supply may be at risk due to geological scarcity, geopolitical issues, trade policy or other factors.

8. Among these important minerals are metals and semi-metals used in the manufacture of cell phones, flat screen monitors, wind turbines, *electric cars,* solar panels, and many other high-tech applications.

9. There is a relatively short history of research on critical minerals (2006 by US).

10. How to measure the criticality of a mineral?

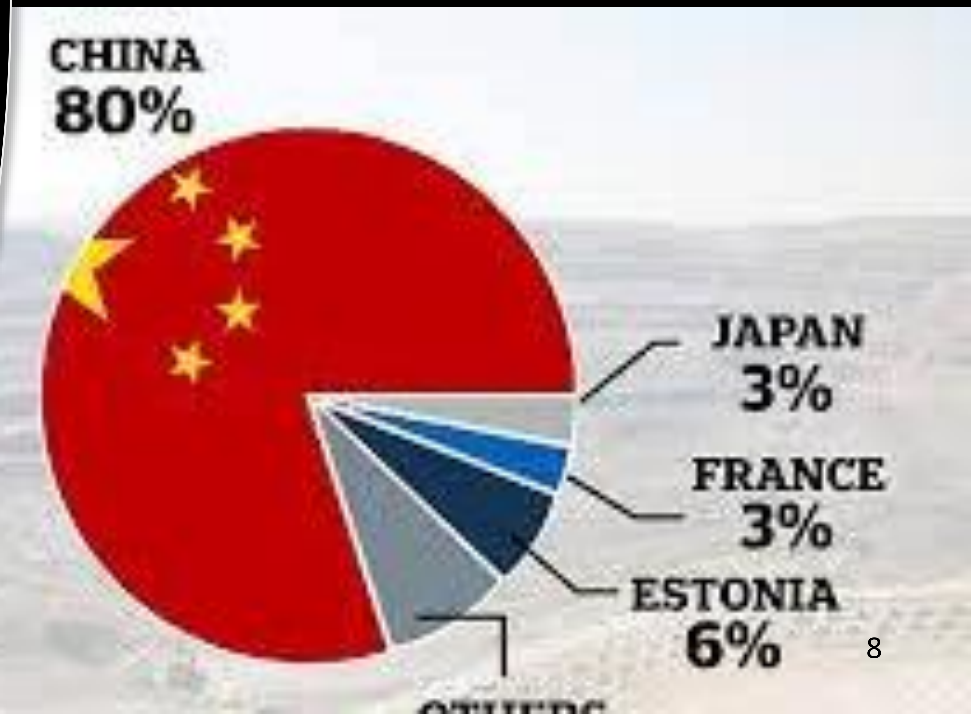
Minerals ranked as most critical by the United States, Japan, Republic of Korea, and the European Union including the United Kingdom, are as follows:

Rare-earth elements (REE),
Gallium (Ga), Indium (In), Tungsten (W),
platinum-group elements (PGE) including platinum (Pt) and palladium (Pd),
Cobalt (Co), Niobium (Nb),
Magnesium (Mg), Molybdenum (Mo),
Antimony (Sb), Lithium (Li),
Vanadium (V), Nickel (Ni),
Tantalum (Ta), Tellurium (Te),
Chromium (Cr) Manganese (Mn).

Why CMs are important?

a) They are more useful than others, being essential and often not substitutable in important technologies, and

b) Some of these minerals are also subject to supply security concerns.



What is the role of Geosciences?

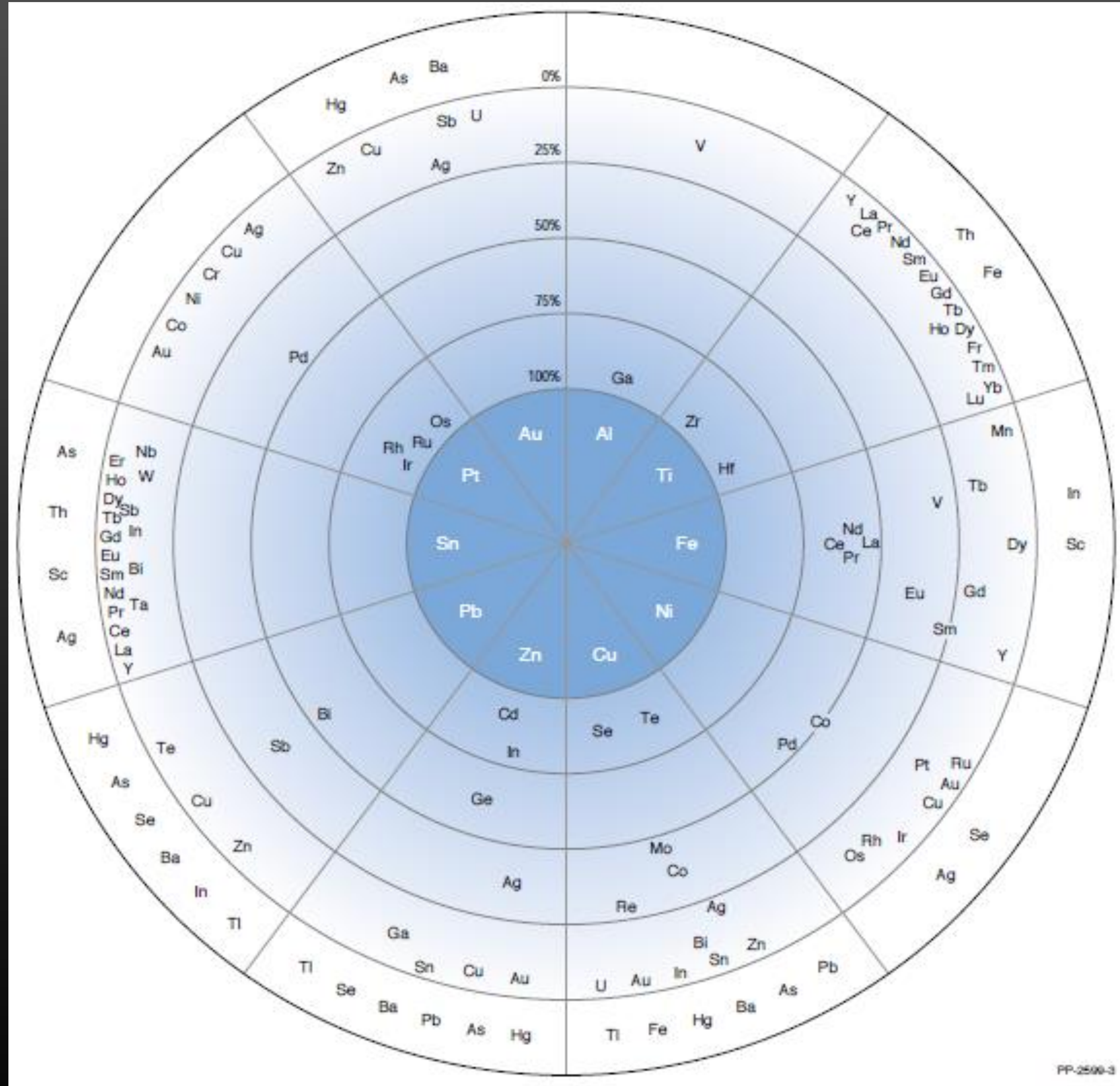
1. Study the formation of critical minerals;
2. Explore for and locate them;
3. Determine how to mine them economically, safely, and with minimal environmental impact;
4. Protect water and ecological resources around the mines; and
5. Reclaim disturbed land after mining.

2. Inevitability of CMs study in Iran

- Many critical minerals are produced as by-products of the mining of major commodities due to the geochemical and geological association of the critical and major ore metals or non-metals. (Example: Indium, gallium, germanium and cadmium in Zinc Sulfates; tellurium, indium, selenium in copper concentrates ; and REEs in iron phosphates)

- It is important to consider the resource and production potential of currently operating mines and smelters by assessing available Iranian ore concentrates for critical mineral abundance.

The wheel of metal companionality indicates the percentage to which various metals are by-products.



3. Demands and Uses of CMs

- Modern technology such as communications, computers and medical technology.

- Low-carbon technologies, for example in renewable energy generation.

Selected minerals often rated as highly critical and their major uses

Mineral	Considered Critical by	Major Applications	Global Production
Antimony	EU, UK, USA	flame retardants, lead acid batteries, plastics catalyst	150 000 t
Cobalt	EU, UK, USA	specialty alloys, batteries, catalysts, tyre adhesives, Pigments	110 000 t
Gallium	EU, UK, USA	renewable energy, Electronics	495 t A
Germanium	EU, UK, USA	infrared devices, fibre optics	134 t
Indium	EU, UK, USA	renewable energy, electronics, specialty alloys, touch screens	680 t
Lithium	UK, USA	renewable energy, electronics, batteries	43 000 t
Niobium	EU, UK, USA	specialty alloys	64 000 t
PGEs	EU, UK, USA	automotive catalysts, chemical catalysts, jewellery, specialty Alloys	~410 t B
Rare earth oxides (REOs)	EU, UK, USA	renewable energy, electric vehicles, military technologies, electronics, specialty alloys, batteries	130 000 t
Rhenium	UK, USA	specialty alloys, chemical catalysts	52 t
Tungsten	EU, UK, USA	specialty alloys	95 000 t

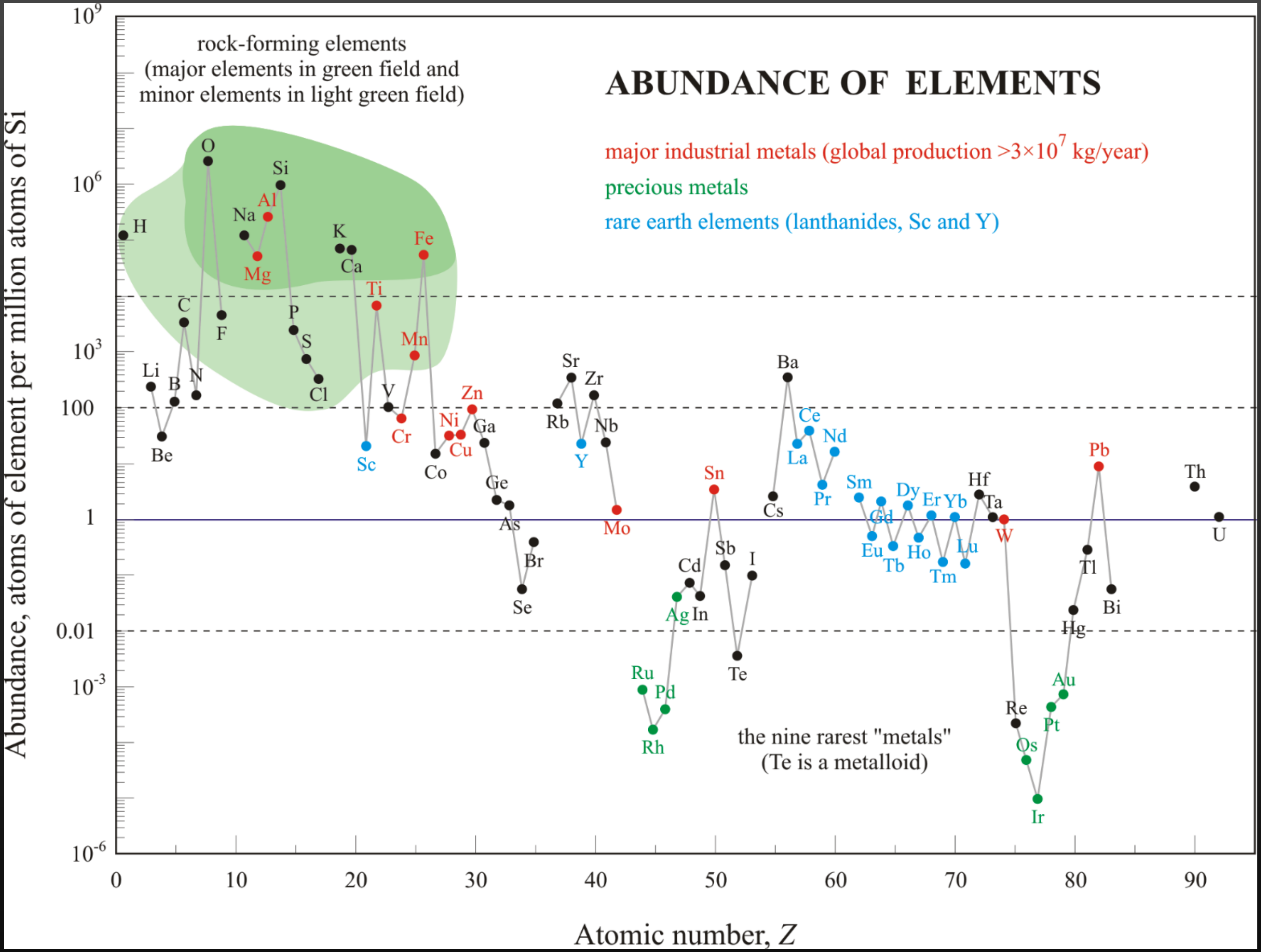
Global mine production and prices of various critical minerals (2017 data), including dominant country

Critical Mineral	Production	Price	Market Value	Largest Producer		
	Tonnes	US$/tonne	US$ million	Country	Tonnes	**Percentage**
REE	130000	186782 A	24 281.7	China	105000	**80.8%**
Phosphate Rock	263000000	75	19 725.0	China	140000000	**53.2%**
Chromite ore	31000000	320	9 920.0	South Africa	15000000	**48.4%**
Cobalt	110000	54454	5 989.9	Congo-DRC	64000	**58.2%**
Tin	290000	20282	5881.9	China	100000	**34.5%**
Platinum*	185.8	30868167	5 735.3	South Africa	135.7	**73.0%**
Palladium*	205.2	27652733	5 674.3	Russia	82.5	**40.2%**
Molybdenum	290000	18000	5 220.0	China	130000	**44.8%**
Tungsten	95000	24500	2 935.3	China	79000	**83.2%**
Graphite	1200000	1400	1 680.0	China	780000	**65.0%**
Vanadium	80000	11464	1637.2	China	43000	**53.8%**
Antimony	150000	8840	1 326.1	China	110000	**73.3%**
Niobium	64000	18000	1 152.0	Brazil	57000	**89.1%**
Rhodium*	23.3	33762058	786.7	South Africa	19.2	**82.4%**
Lithium	43000	13900	597.7	Australia	18700	**43.5%**
Indium	720	360000	259.2	China	310	**43.1%**
Tantalum	1300	193000	250.9	Rwanda	390	**30.0%**
Iridium*	8.2	29163987	239.1	South Africa	nd	**nd**
Germanium	134	1358000	182.0	China	88	**65.7%**
Bismuth	14000	10582	148.1	China	11000	**78.6%**
Beryllium	230	630000	144.9	USA	170	**73.9%**
Gallium	495	565000	117.8	China	nd	**nd**
Rhenium	52.0	1550000	80.6	Chile	27.0	**51.9%**
Selenium	3300	23810	78.6	China	930	**28.2%**
Ruthenium*	37.5	1961415	73.6	South Africa	nd	**nd**
Cadmium	23000	1700	39.1	China	.8200	**35.7%**
Tellurium	420	36000	15.1	China	280	**66.7%**
Strontium	202000	73	14.7	Spain	90000	**44.6%**
Hafnium	nd	912000	nd	nd	nd	**nd**
Scandium	**nd**	**350000 B**	**nd**	**nd**	**nd**	**nd**

Critical Mineral	Production (t)		% difference	Major Metal / Mineral	Production (t)		% difference
	2000	2017			2000	2017	
Gallium (total)	110	495	450	Garnet	291 000	1 100 000	**378**
Tellurium	125	420	336	Alumina	51 700 000	130 000 000	**251**
Cobalt	33 300	110 000	330	Titanium-Rutile conc.	390 000	900 000	**231**
Lithium	14 000	43 000	307				
Ruthenium*	13.8	37.5	271	Iron Ore	1 060 000 000	2 400 000 000	**226**
Tungsten	37 400	95 000	254	Boron	4 370 000	9 800 000	**224**
Bismuth	5880	14 000	238	Bauxite	135 000 000	300 000 000	**222**
Selenium	1410	3300	234	Manganese Ore	7 280 000	16 000 000	**220**
Molybdenum	129 000	290 000	225	Mercury	1350	2500	**185**
Niobium	~29 118 A	64 000	220	Nickel	1 250 000	2 100 000	**168**
Chromite ore	14 400 000	31 000 000	215	Zircon conc.	1 040 000	1 600 000	**154**
Indium	335	720	215	Lead	3 100 000	4 700 000	**152**
Iridium*	3.9	8.2	211	Zinc	8 730 000	13 200 000	**151**
Graphite	571 000	1 200 000	210	Copper	13 200 000	19 700 000	**149**
Phosphate Rock	133 000 000	263 000 000	198	Sulfur	57 200 000	83 000 000	**145**
Germanium	71	134	189	Titanium-Ilmenite conc.	4 300 000	6 200 000	**144**
Vanadium	43 000	80 000	186				
Rhenium	28.4	52.0	183	Silver	17 700	25 000	**141**
REE	83 500	130 000	156	Uranium	42 457	59 531	**140**
Tantalum	836	1300	156	Fluorspar	4 520 000	6 000 000	**133**
Antimony	118 000	150 000	127	Barite	6 200 000	7 700 000	**124**
Tin	238 000	290 000	122	Gold	2550	3150	**124**
Cadmium	19 700	23 000	117				
Platinum*	164.5	185.8	113				
Rhodium*	23.9	23.3	98				
Palladium*	242.6	205.2	85				
Beryllium	280	230	82				
Strontium	520 000	202 000	39				
Hafnium	nd	nd	nd				
Scandium	nd	nd	nd				
		Average	**199**			**Average**	**182**

Percentage difference of world mine production from 2000 to 2017 for major and critical minerals

4. What are Rare Earth Elements(REE)s?



A group of 17 "NOT REALLY RARE" elements in periodic table.

REEs as “CRITICAL METALS”:

Utilize to produce

- CO_2-free power generation (Solar and wind turbines) and storage systems.
- Efficient lighting and transportation systems.

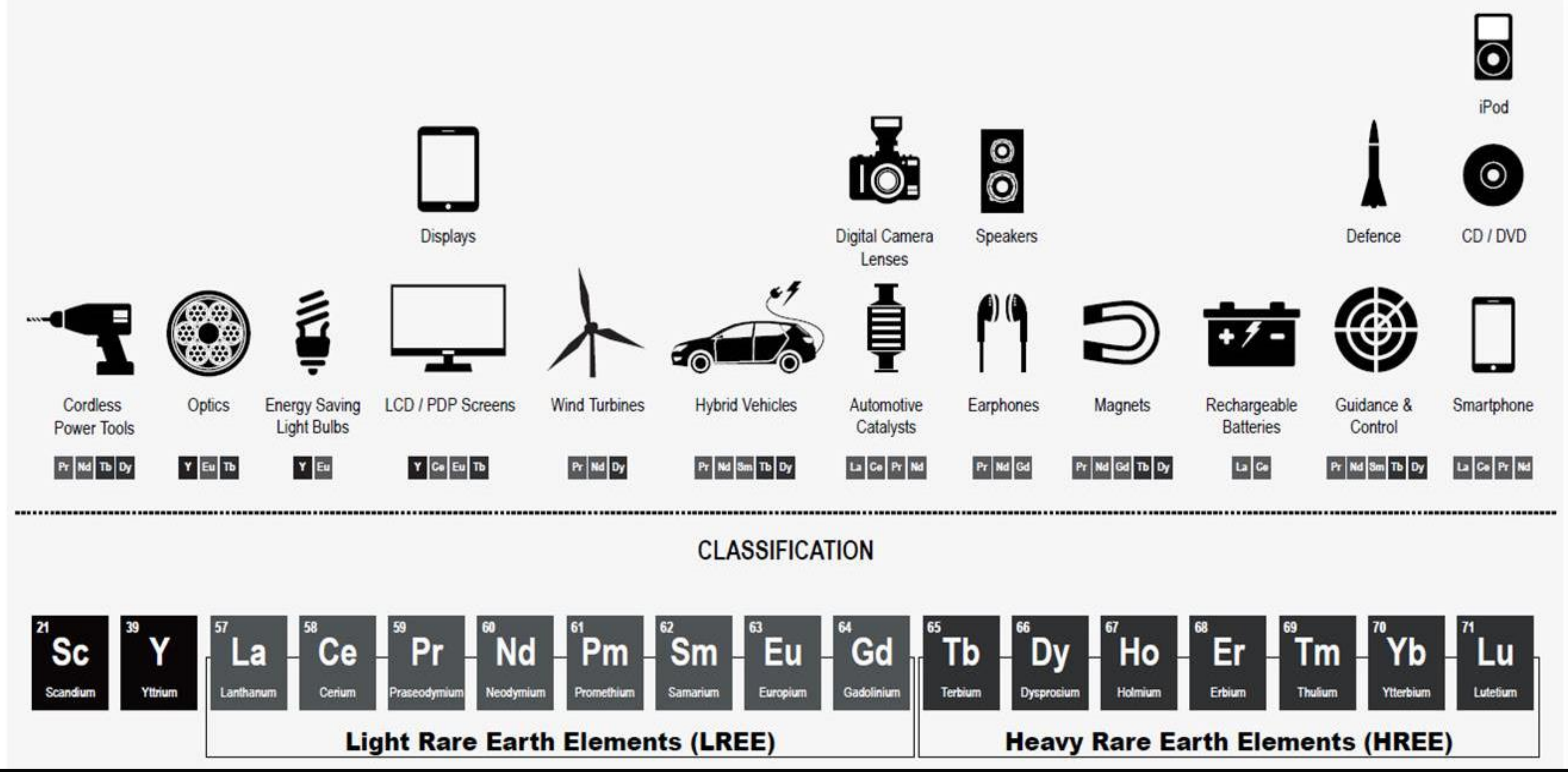
REEs direct Usage overview

Rare earths role in various sectors*.

Various sectors	Rare earth elements (REEs)
1) Green energy sector	
Lighting	Eu, Y
Rechargeable batteries	La, Ce
Wind power	Nd, Pr, Dy
Hybrid vehicles	Nd, Pr, Sm, Dy, Tb
2) Lifestyle sector	
LCD/PDP screens	Y, Ce, Eu, Tb
Magnetic resonance imaging	Nd, Gd
Cordless power tools	Nd, Pr, Sm, Dy, Tb
Cellphones, iPods, CDs-DVDs	Nd, Pr, Ce, La
3) Defense sector	
Optics	Eu, Y, Tb
Surveillance and protection	Nd, Y, La, Eu, others
Lasers	Dy, Tb
Aircraft materials	Y, others
Guidance and control	Nd, Pr, Sm, Dy, Tb
Power and communications	Nd, Pr, Sm, Dy, Tb
Microwave communications	Nd, Pr, Dy, Tb, Eu
Solar transducers	Nd, Y, La, Eu, others

REEs direct Usage overview

In-direct use: Petrogenic studies, …

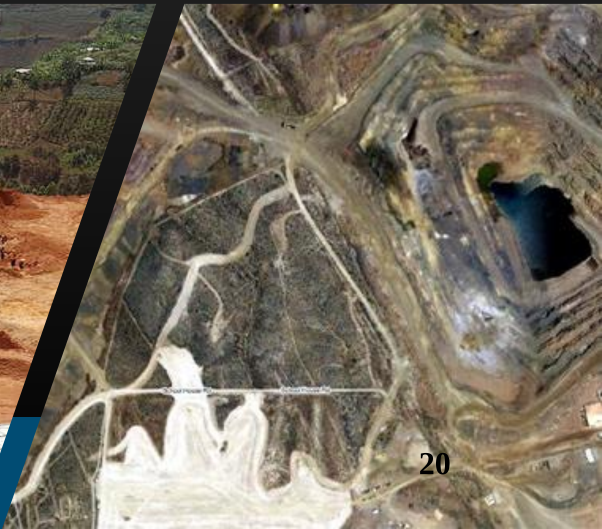


Rare Earth Deposits

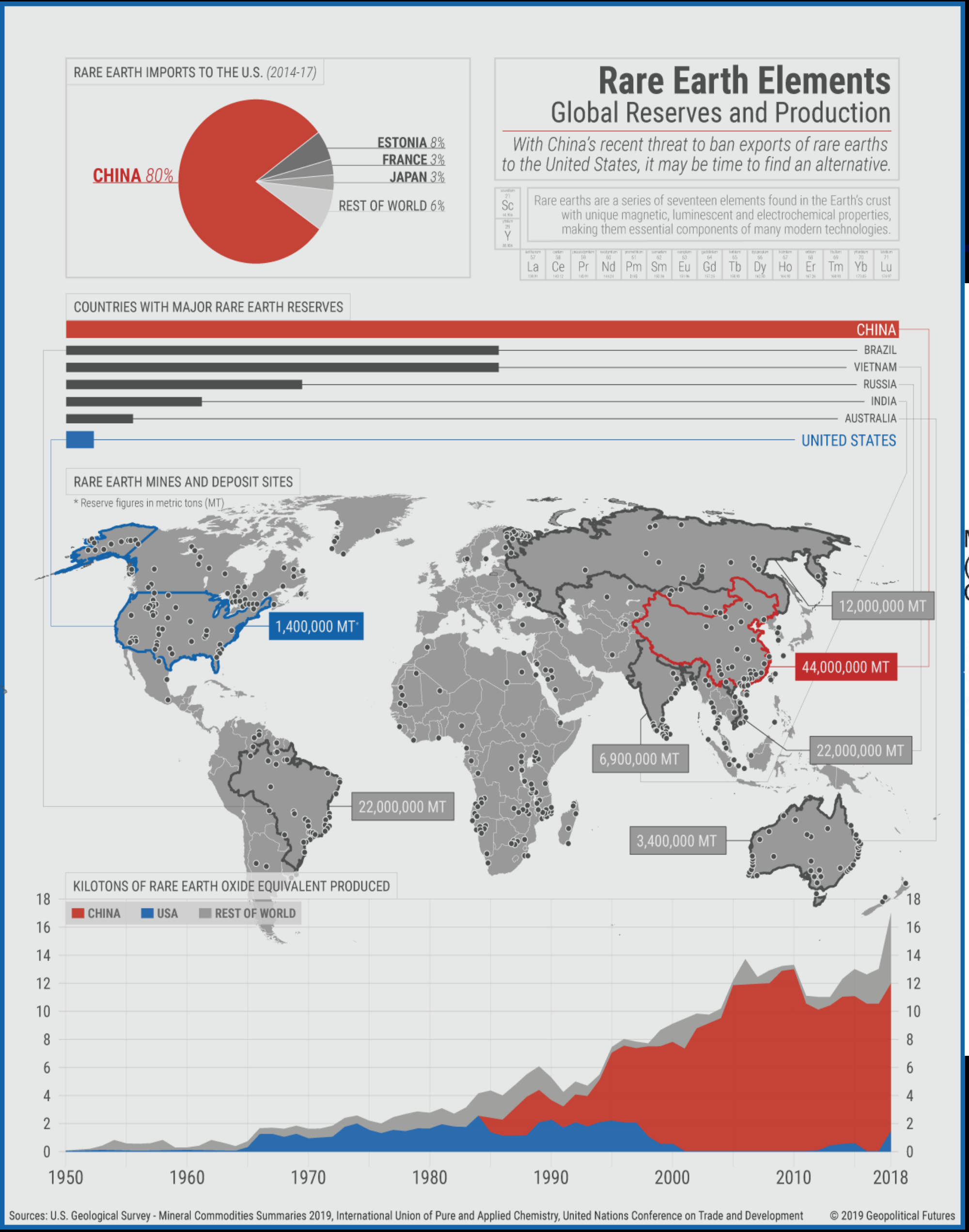
1. Igneous deposits;
   - Carbonatite; (Bayan Obo and Mountain Pass)
   - Peralkaline-related rocks; (Lovozero)
   - Iron Oxide-Apatite (IOA);
2. Hydrothermal deposits,

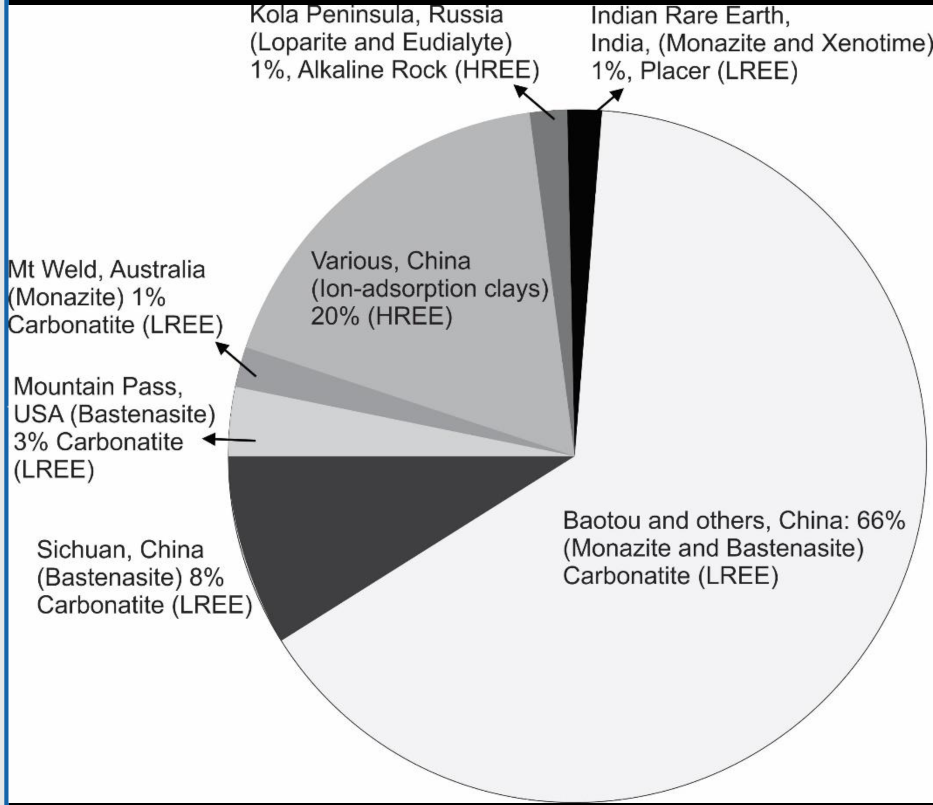
   Monazite + Apatite hydrothermal veins.
3. Residual
   - Placer Deposits
   - Ion-Adsorption deposits (IAD)s

➢ From bauxite and phosphate



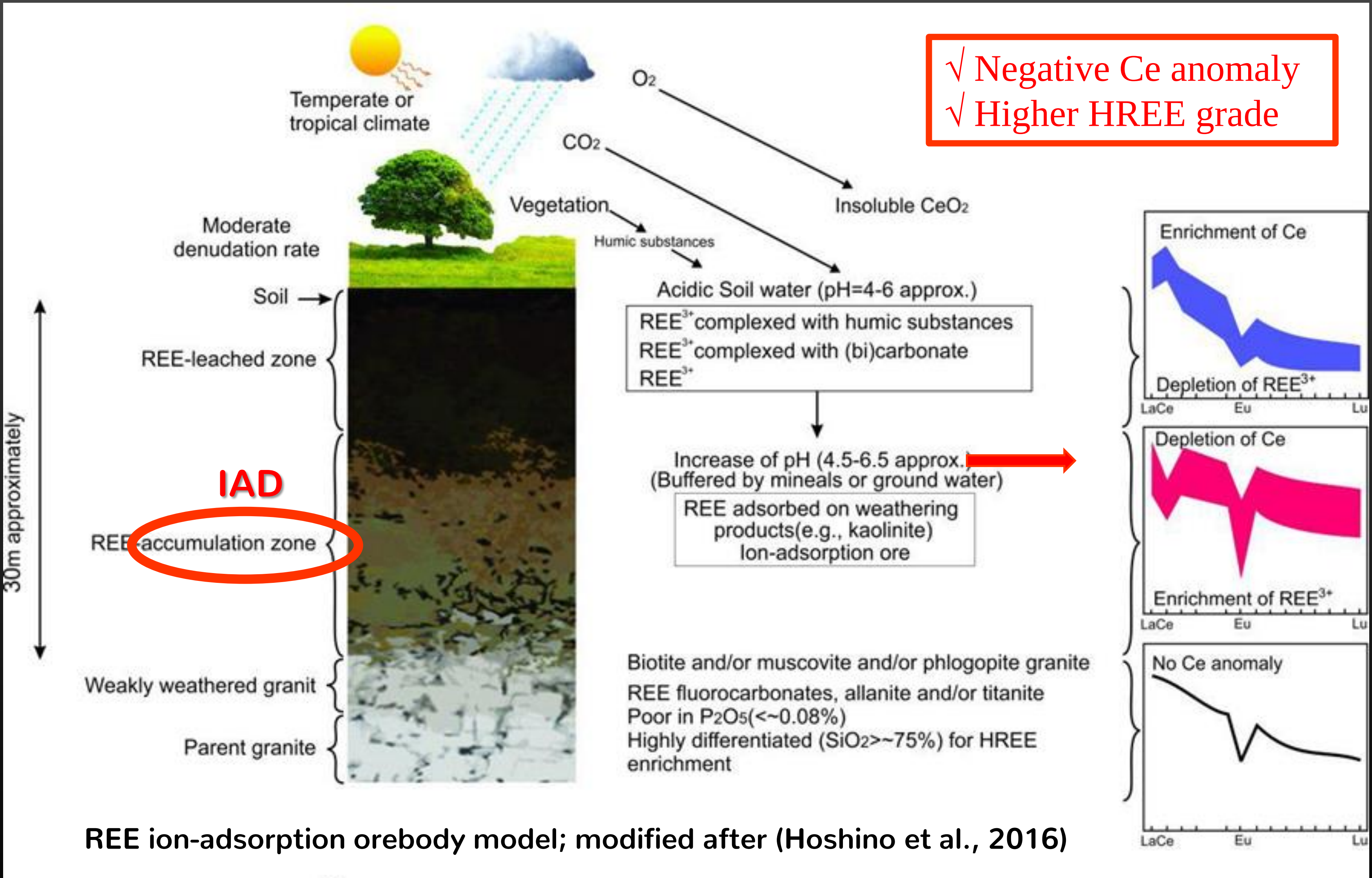
REEs Global Production and Reserves





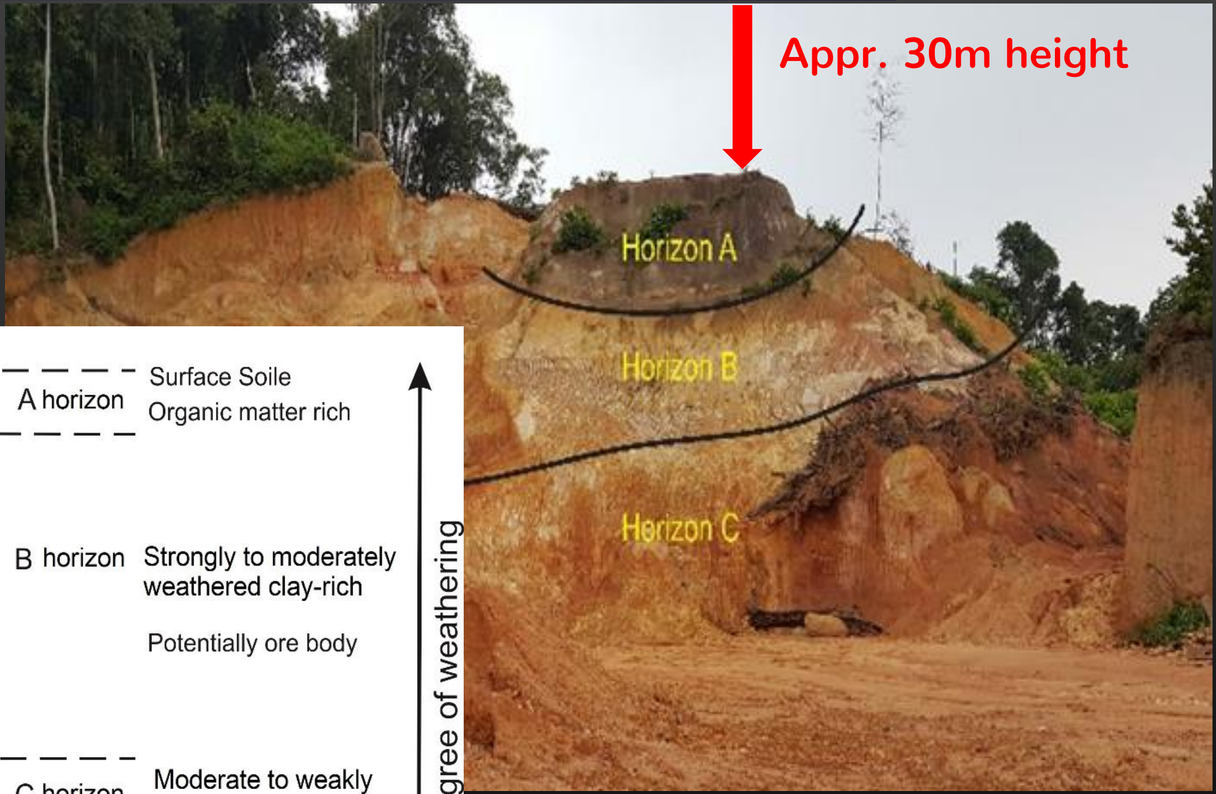
Where can find more?

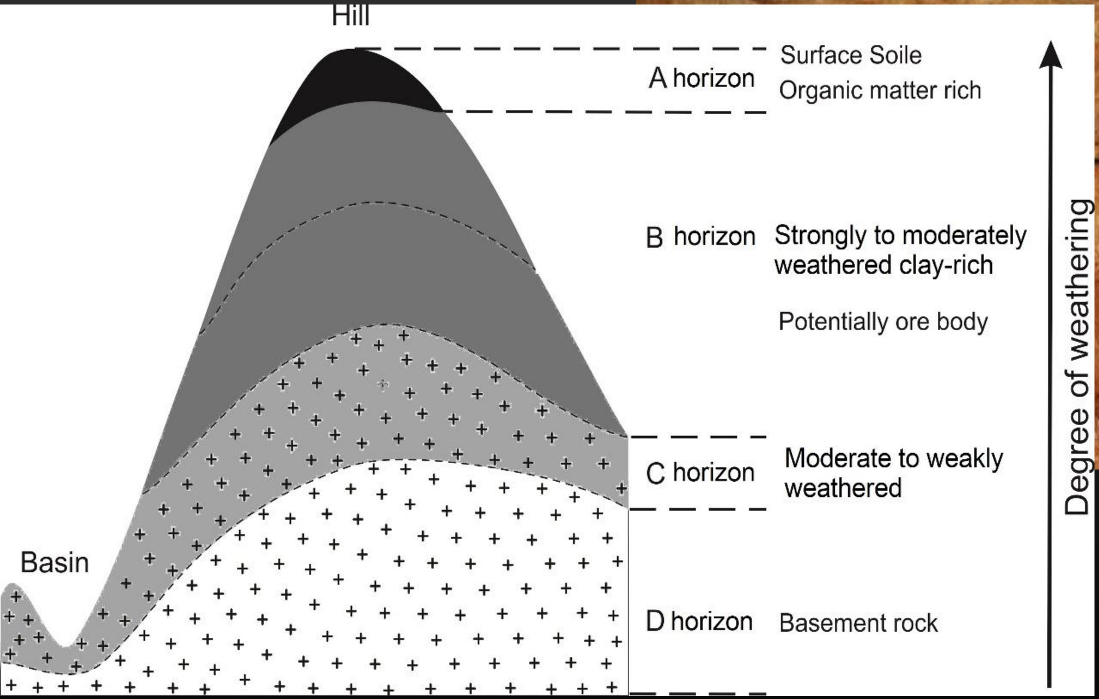
REE Ion-Adsorption Deposits (IAD)s



REE ion-adsorption orebody model; modified after (Hoshino et al., 2016)

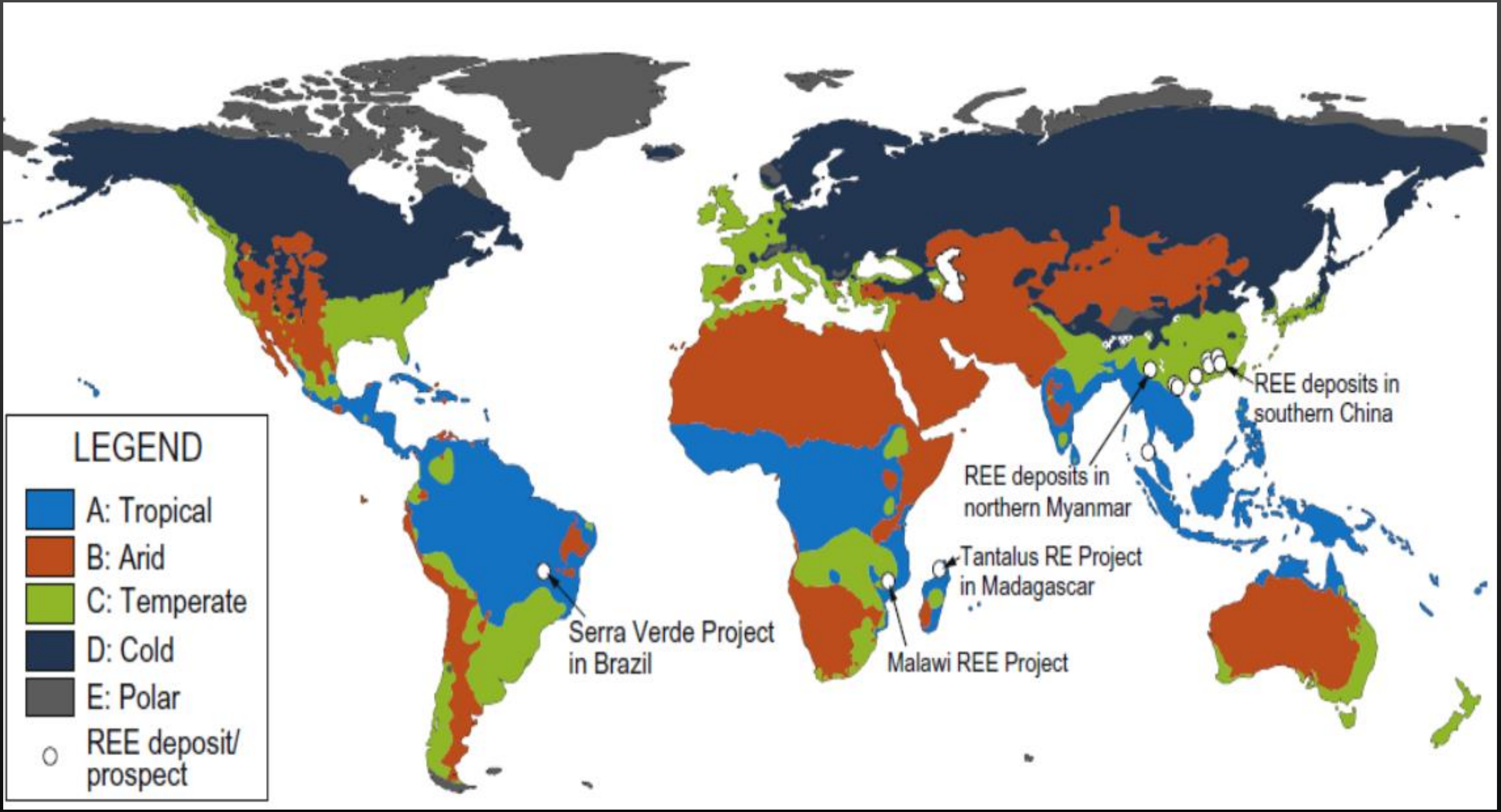
REE Ion-Adsorption Deposits (IAD)s





Sampling area; Weathering crust of granite representation profile; modified after (Hoshino et al., 2016)

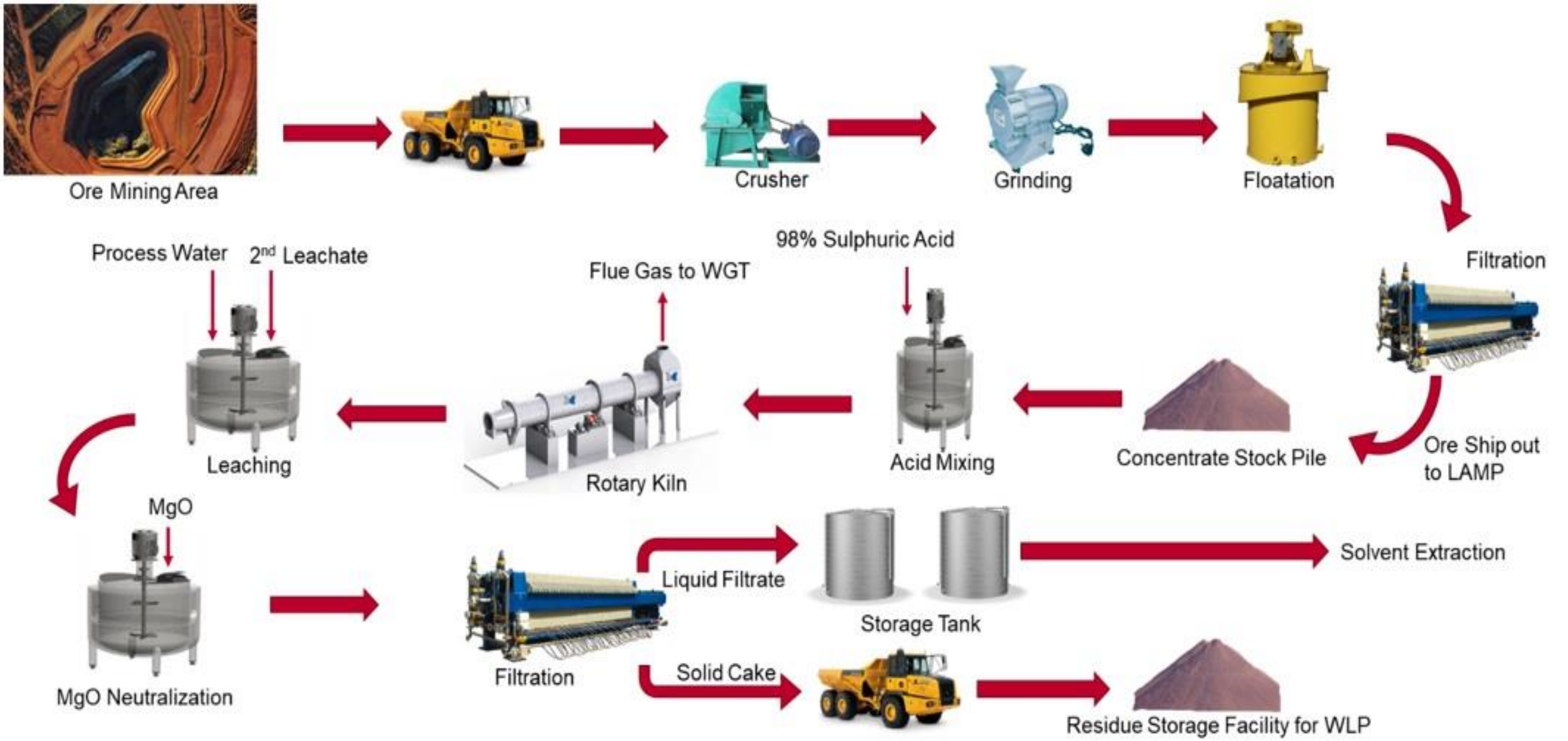
Ion-adsorption REE projects around the world



Ion-adsorption REE projects around the world based on climate variation; modified after (Hoshino et al., 2016; Peel et al., 2006)).

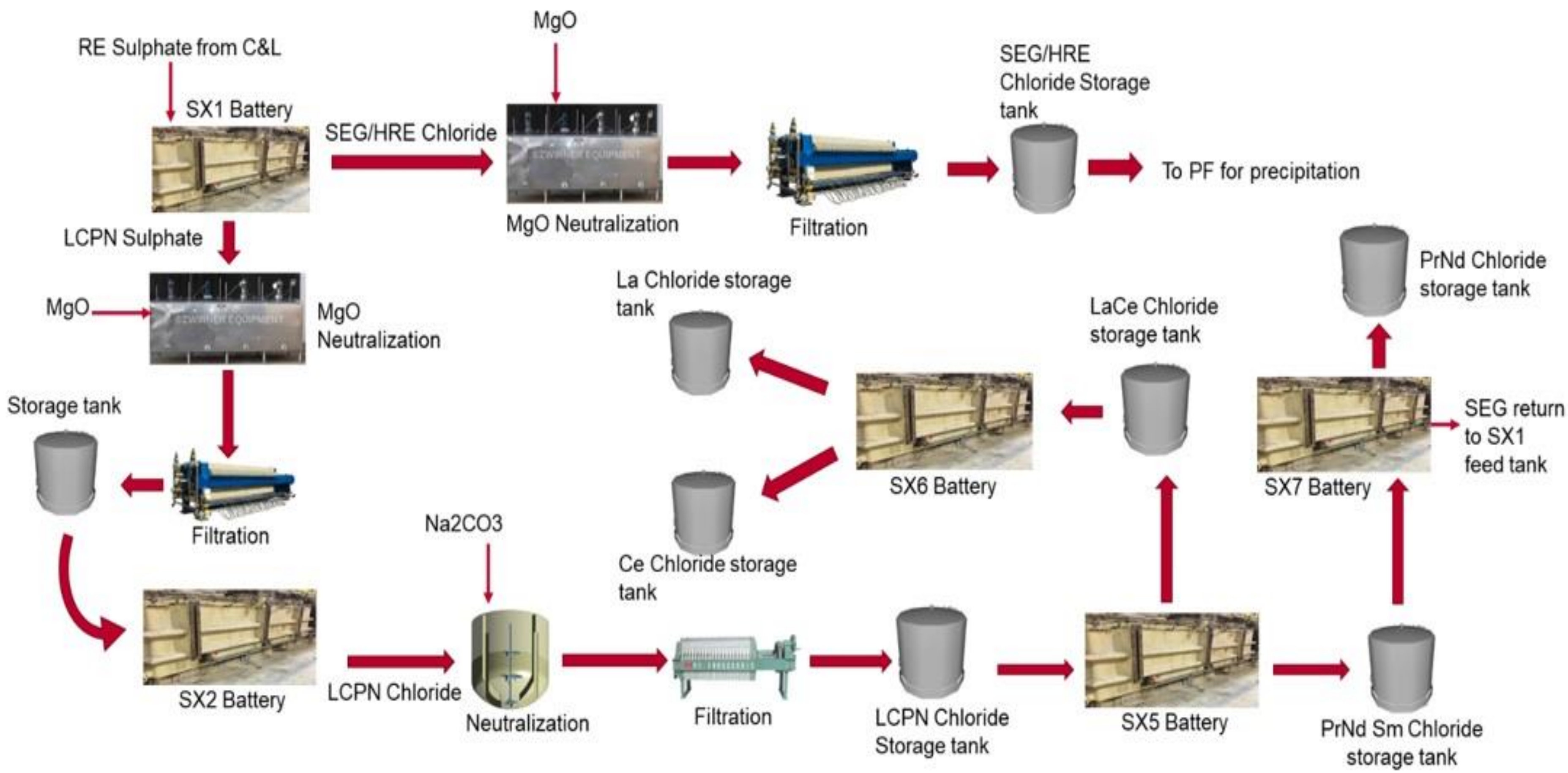
Lynas Advanced Material Plant (LAMP)

Cracking and Leaching Process Overview:

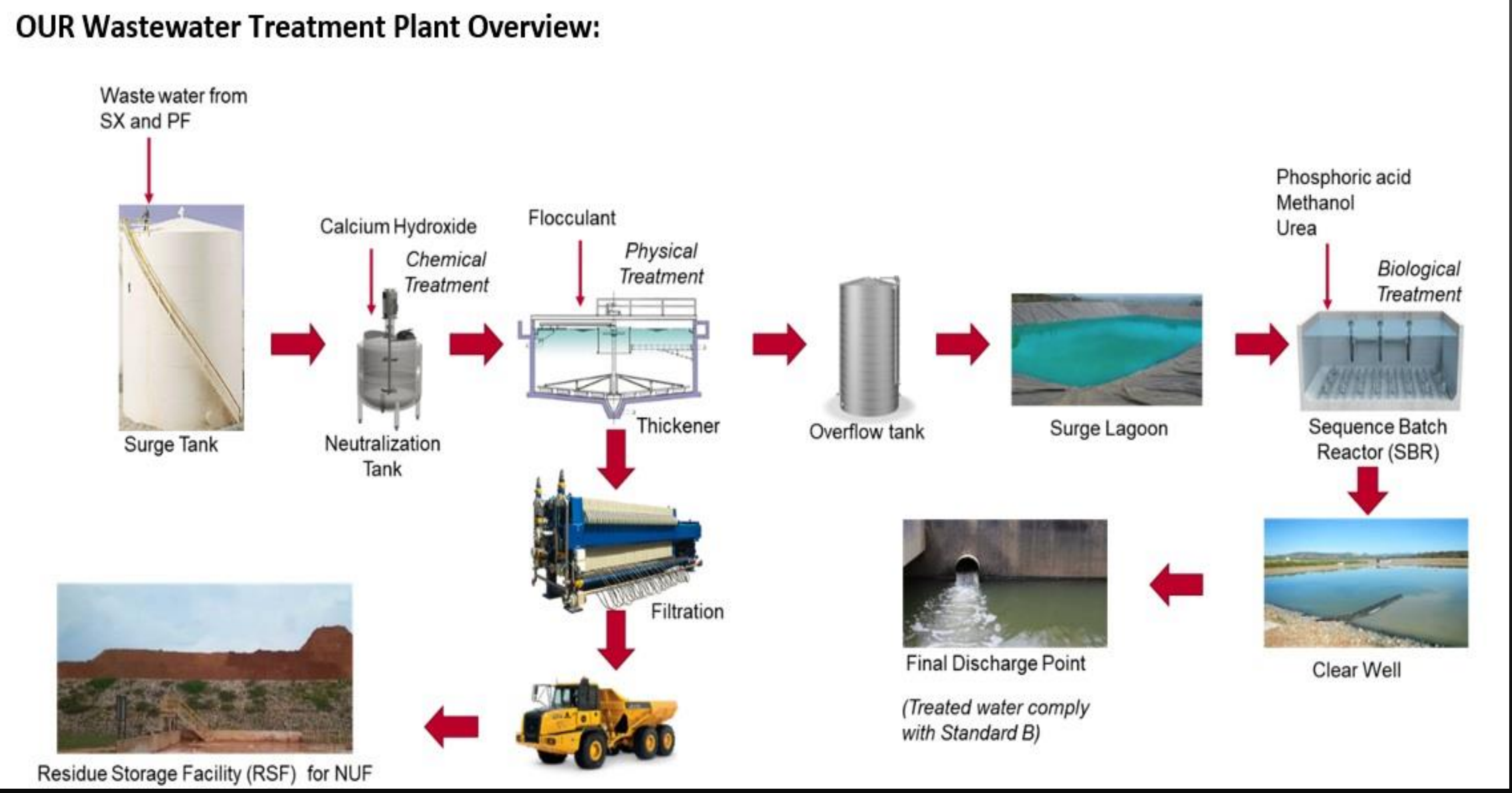


Lynas Advanced Material Plant (LAMP)

Solvent Extraction Process Overview:

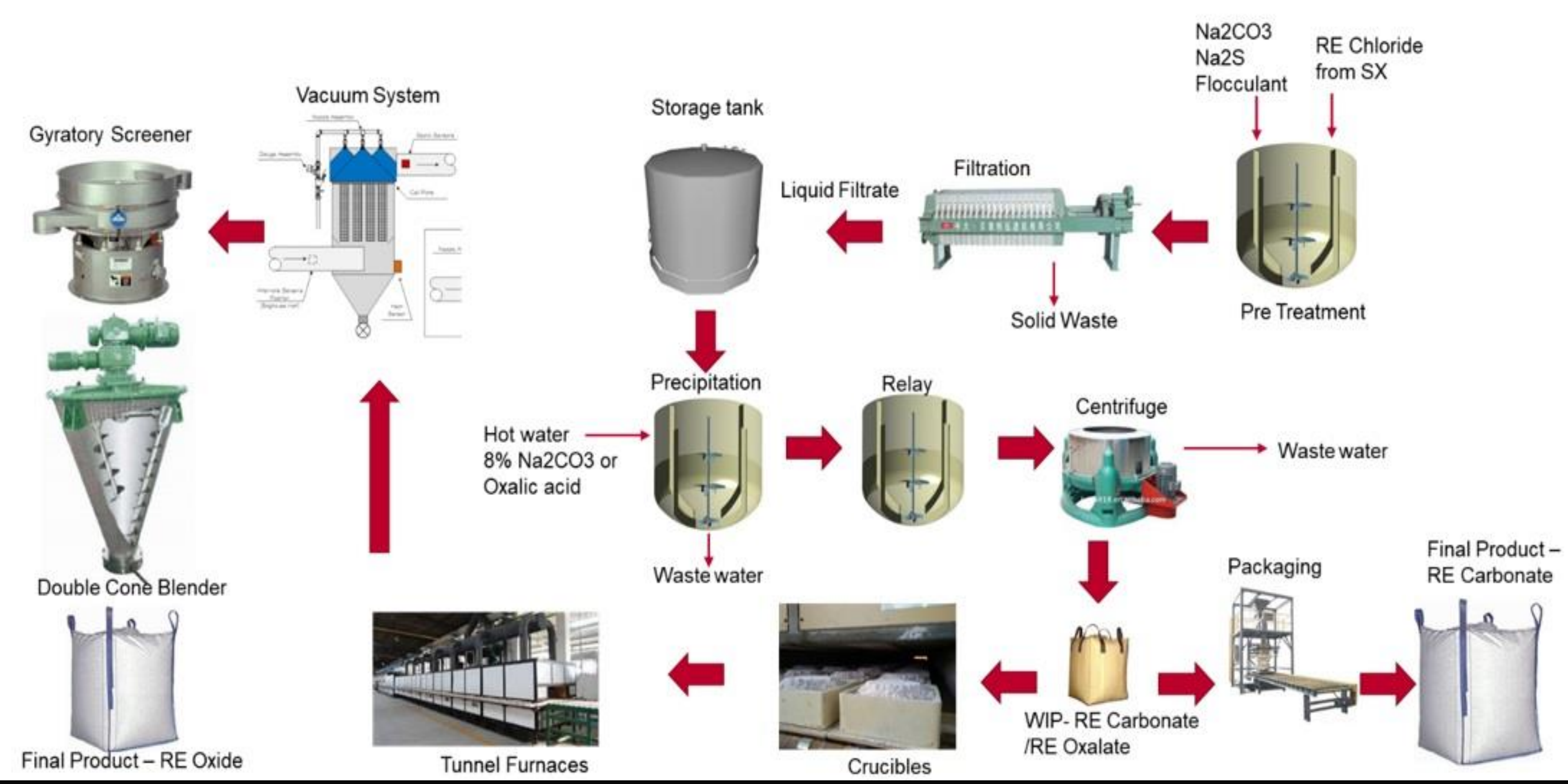


Lynas Advanced Material Plant (LAMP)



Lynas Advanced Material Plant (LAMP)

Product Finishing Process Overview:



Ion-adsorption REE Research in Malaysia

Field Investigation
- ✓Geological survey
- ✓Geological sampling

Sample preparation
- ✓Crushing by Jaw & cone crusher
- ✓Milling by roll mill
- ✓Screening to <75 micron

Characterization

OM, XRD, FTIR, XRF, LOI, SEM/EDX, ICP-MS

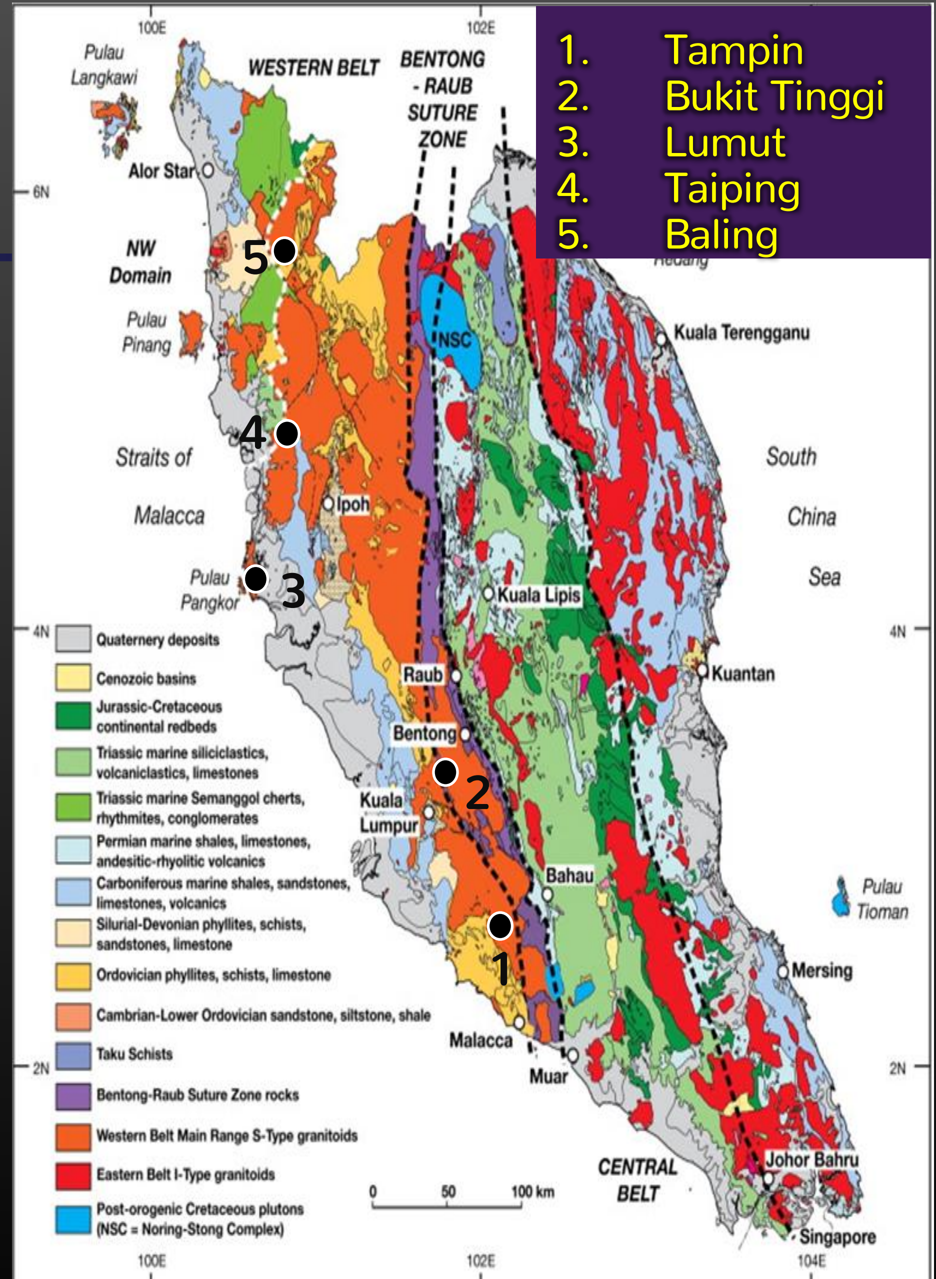
CEC determination
- ✓Sodium Acetate method
- ✓Methylene blue dye test

Trial Leaching Experiments
- ✓using Ammonium Sulphate

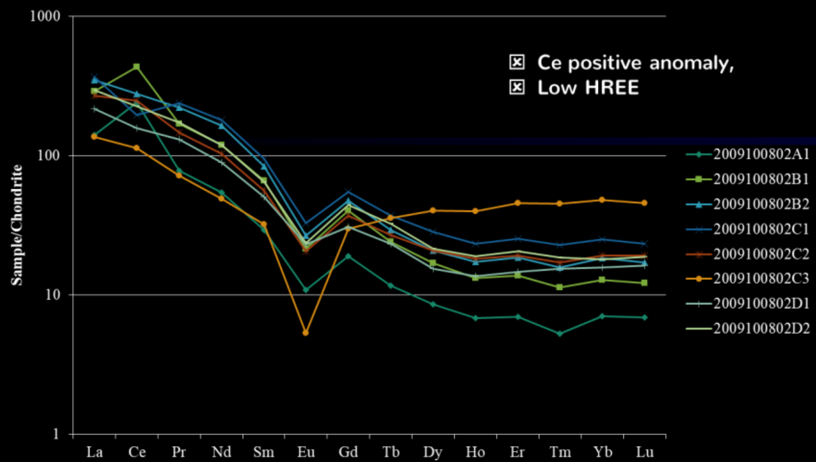
Results and Discussion

Why Dinding district?

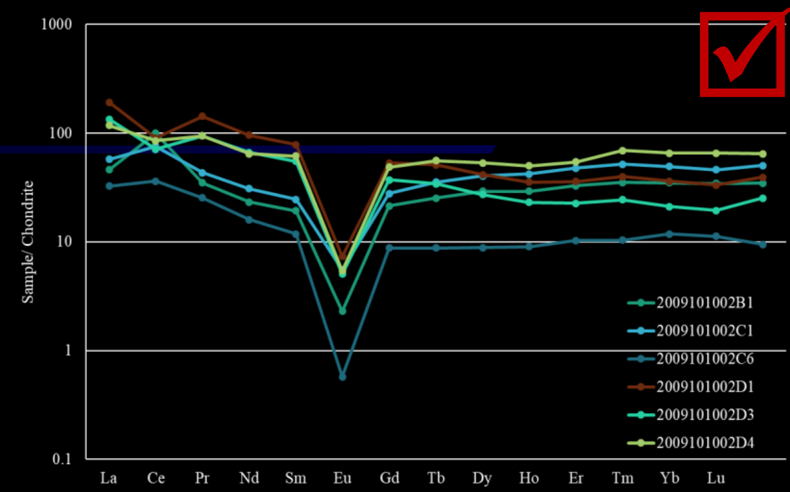
1. The Highest HREE/LREE among the areas. (Flat or near to flat chondrite plot).
2. Relatively high TRE
 (up to 7 times enrichment).
3. An area with more Ce-depletion samples (REE-rich, Ce negative anomaly)
4. High REE concentration is not only because of high Ce concentration.



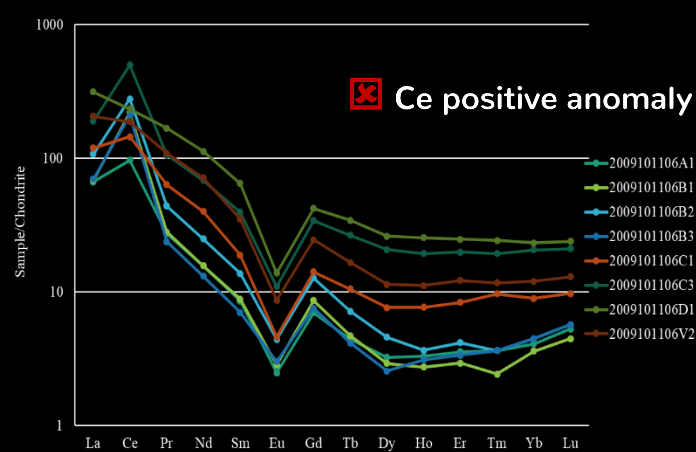
4. Taiping; 20 samples



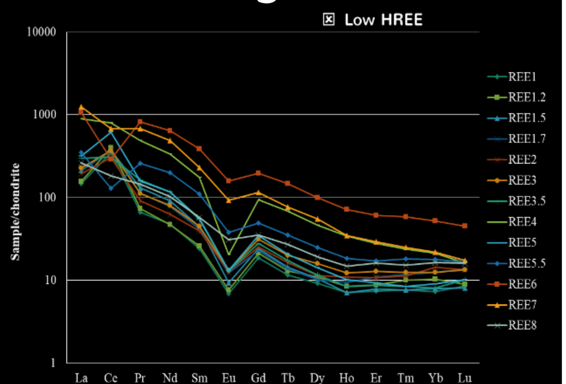
3. Lumut; 48 samples



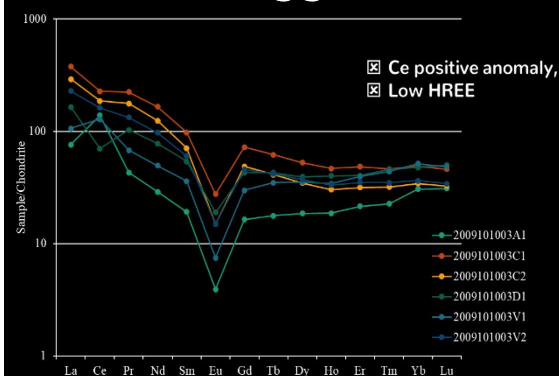
1. Tampin; 23 samples



5. Baling; 13 samples

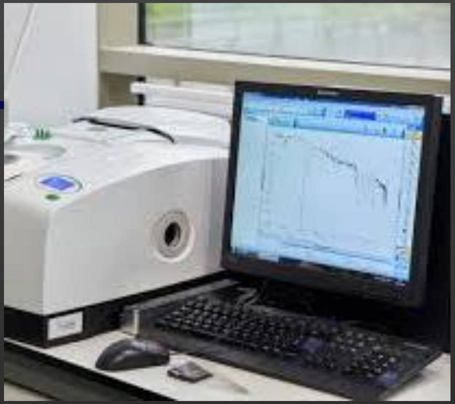


2. Bukit Tinggi; 20 samples



Geological Sampling

Field Investigation



Characterization

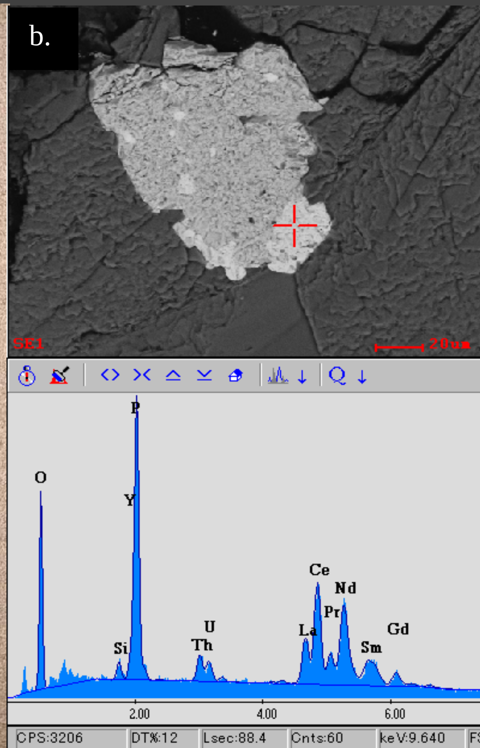
Characterization

Characterization concept	Applied technique(s)
Mineralogy and Petrography	Optical Microscopy **(OM)**
	Fourier-Transform Infrared **(FTIR)** Spectroscopy
	X-ray powder diffraction **(XRD)**
Chemical Composition	X-ray Fluorescence Spectroscopy **(XRF)**
	Inductively coupled plasma-mass spectrometry **(ICP-MS)**
Mineral Chemistry	**OM** & Scanning Electron Microscopy **(SEM)** / Energy Dispersive X-ray Spectroscopy **(EDX)**
Cation Exchange Capacity (CEC)	**Ammonium Acetate Method** **Methylene Blue Dye Test**

Mineral chemistry of granite (LU parent rock)

a.

b.



Standardless Quantitative Data

Matrix Correction: ZAF

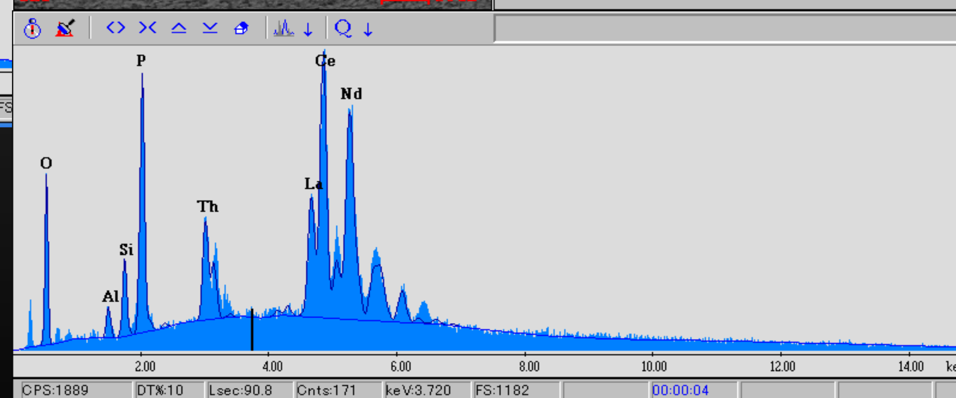
Element	Wt%	At%	Net Inte	Bgnd
OK	13.58	45.32	142.18	6.92
SiK	1.05	2.00	17.80	23.01
YL	3.18	1.91	27.66	23.10
PK	15.38	26.50	291.31	23.07
ThM	5.33	1.23	34.25	26.00
UM	1.42	0.32	9.02	23.16
LaL	12.40	4.76	64.73	22.90
CeL	30.63	11.67	154.64	24.25
PrL	3.09	1.17	15.05	23.69
NdL	11.77	4.36	54.39	23.15
SmL	1.54	0.55	6.28	23.73
GdL	0.63	0.22	2.18	22.56

c.

Standardless Quantitative Data

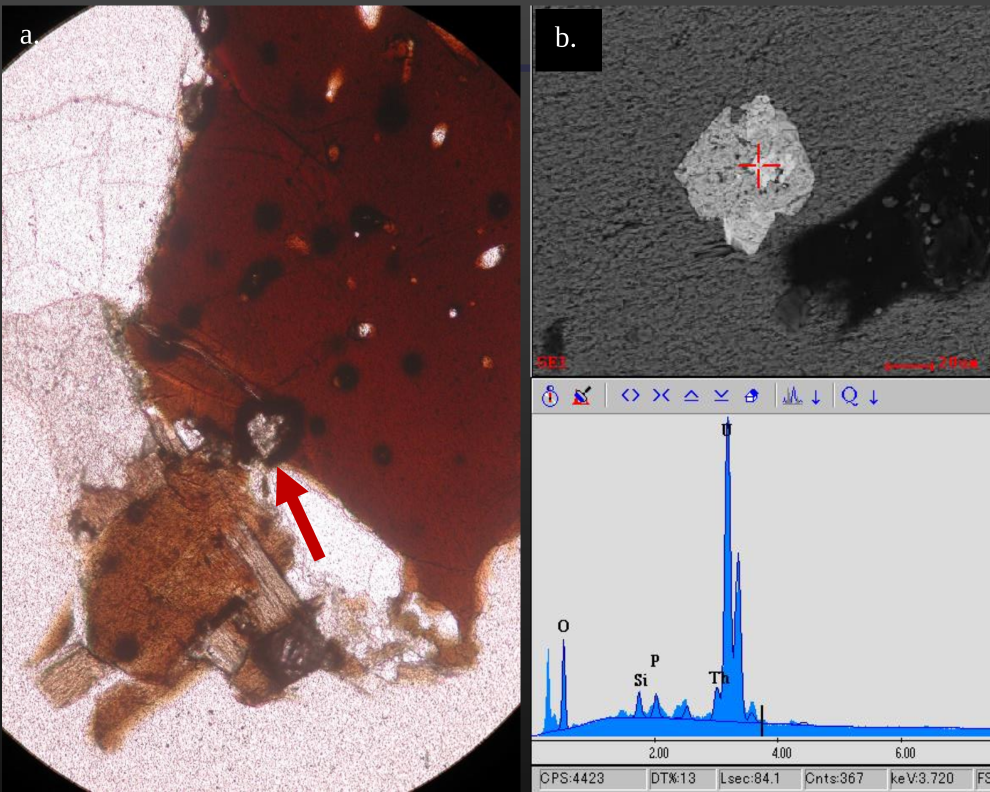
Matrix Correction: ZAF

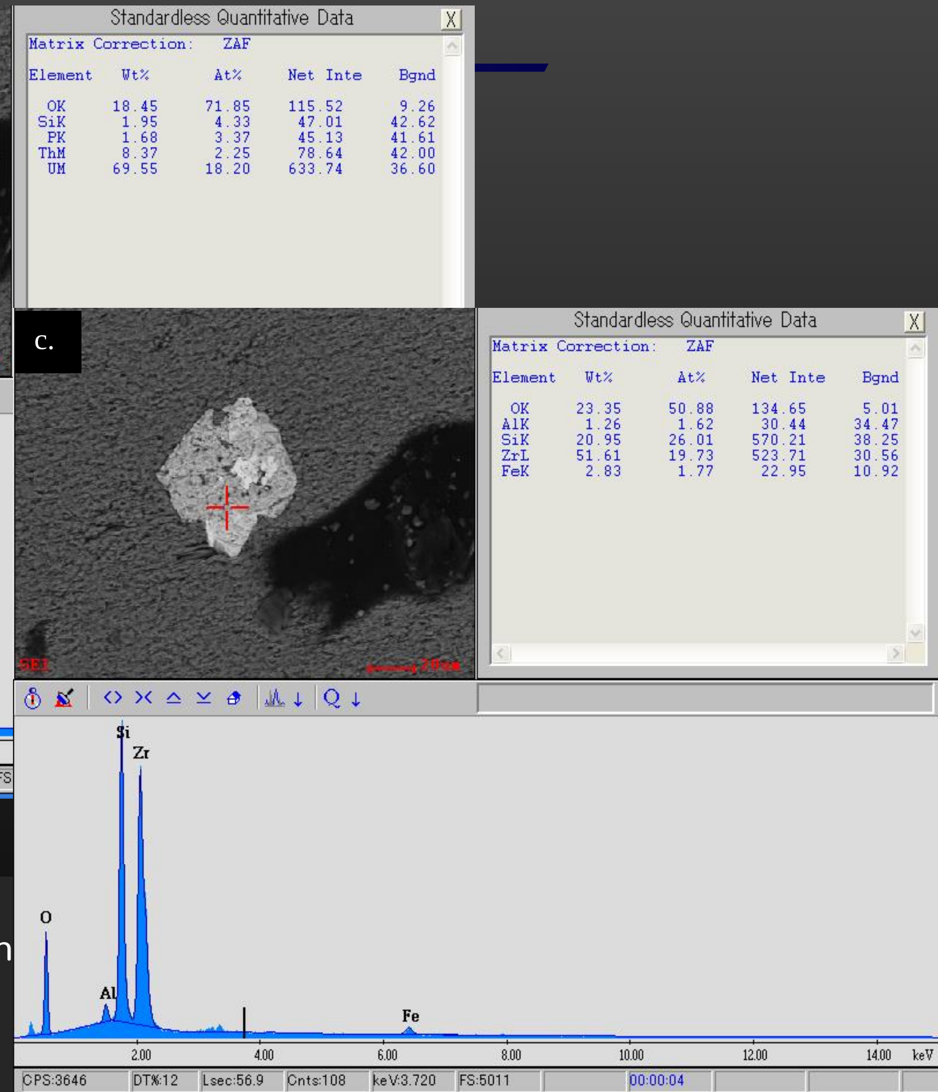
Element	Wt%	At%	Net Inte	Bgnd
OK	5.74	27.24	35.33	1.19
AlK	1.24	3.50	8.50	3.97
SiK	2.74	7.40	23.49	5.13
PK	8.00	19.60	78.27	6.52
ThM	10.02	3.28	37.04	14.00
LaL	16.32	8.92	48.57	16.69
CeL	40.46	21.92	116.55	17.67
NdL	15.47	8.14	40.98	16.83



Photomicrographs taken under an optical microscope showing (a) burning feature (Metamict texture) resulted by radioactivity, backscattered electron by SEM presenting (b) xenotime and (c) monazite.

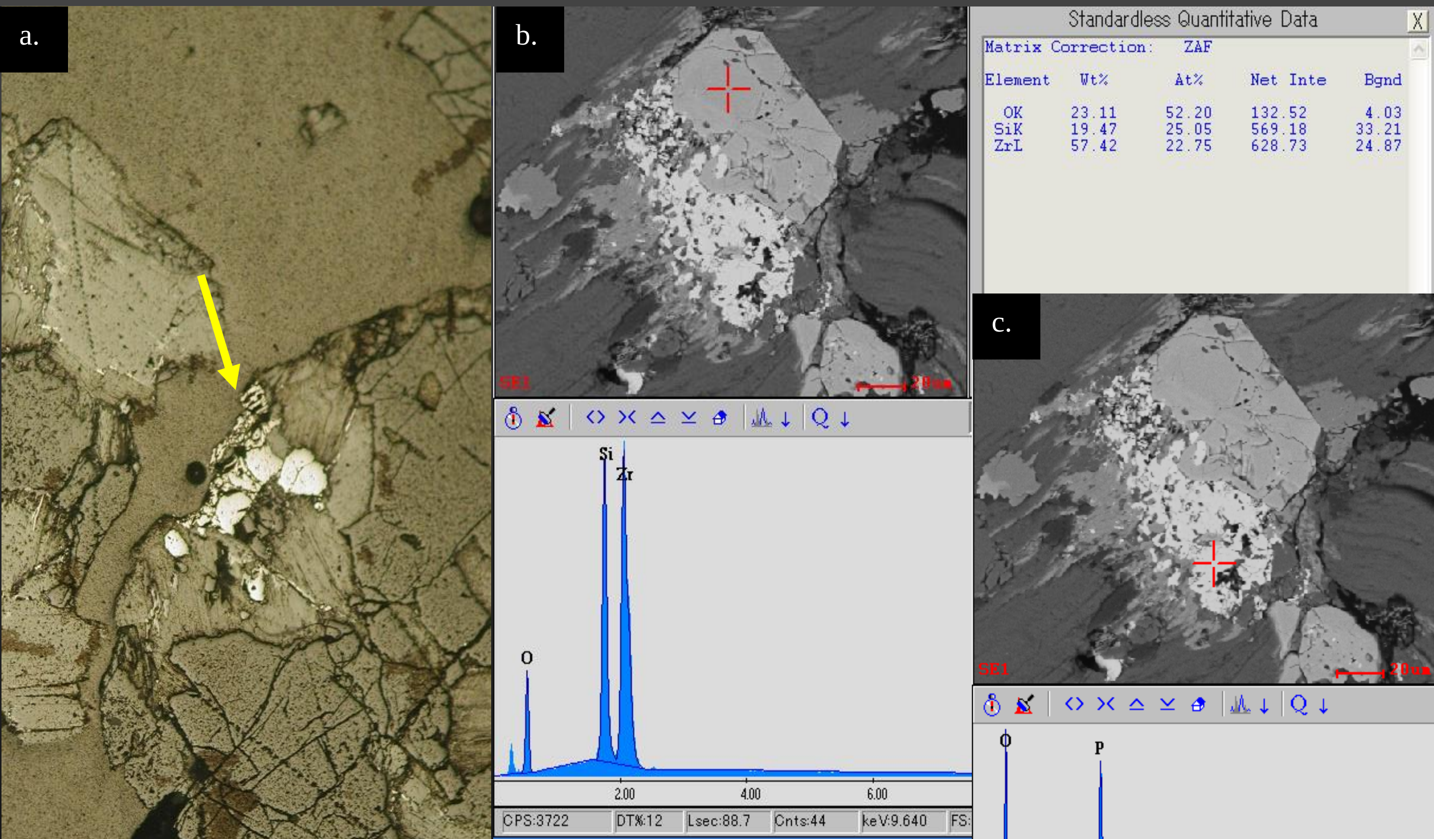
Mineral chemistry of granite (LU parent rock)

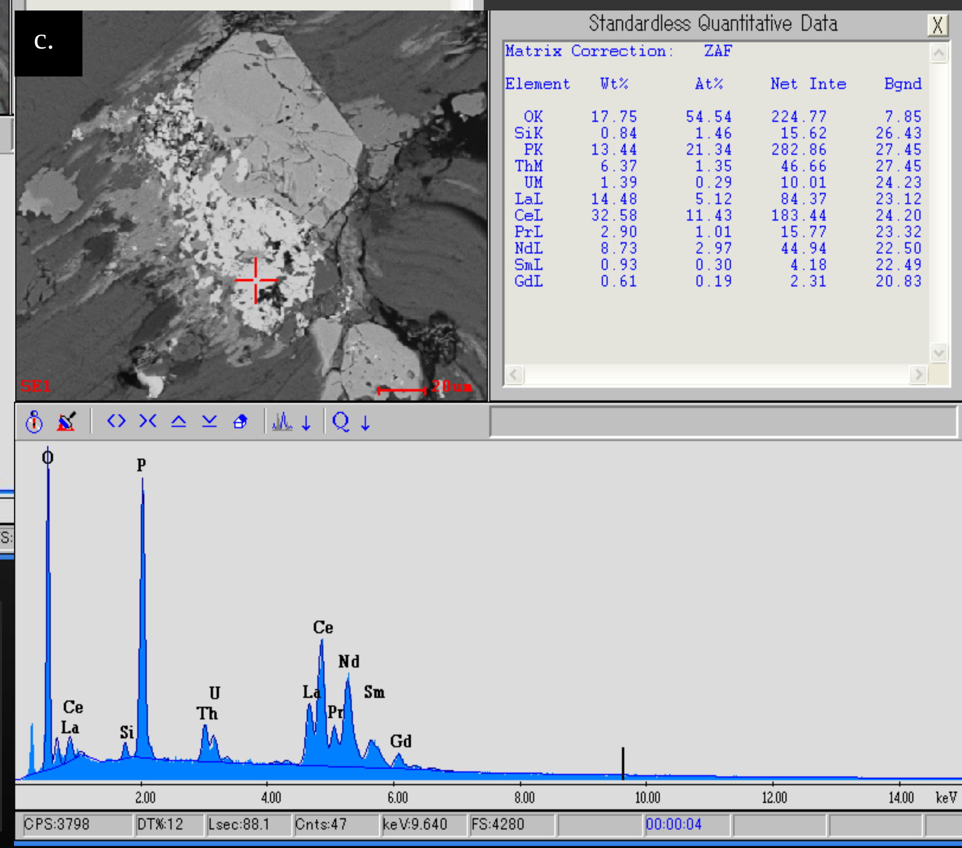




Photomicrographs taken under an optical microscope with (a) burning feature and backscattered electron by SEM from (b and c) REE-bearing minerals of Lumut parent rock consisting of (c) zircon with (b) U and Th substitution (allanite).

Mineral chemistry of granite (TM parent rock)

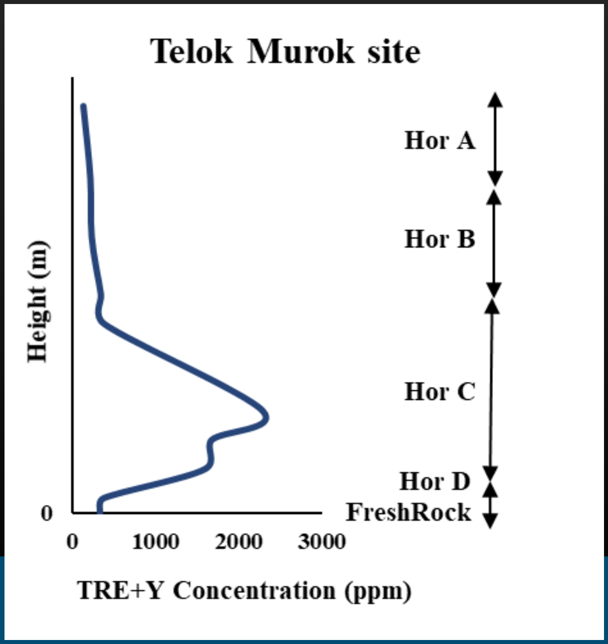




(a) Photomicrographs taken under an optical microscope (polished section) and backscattered electron by a scanning electron microscopes of (b and c) REE-bearing minerals of Telok Murok parent rock consisting of (b) zircon and (c) monazite

Whole-Rock and REE geochemistry (TM)

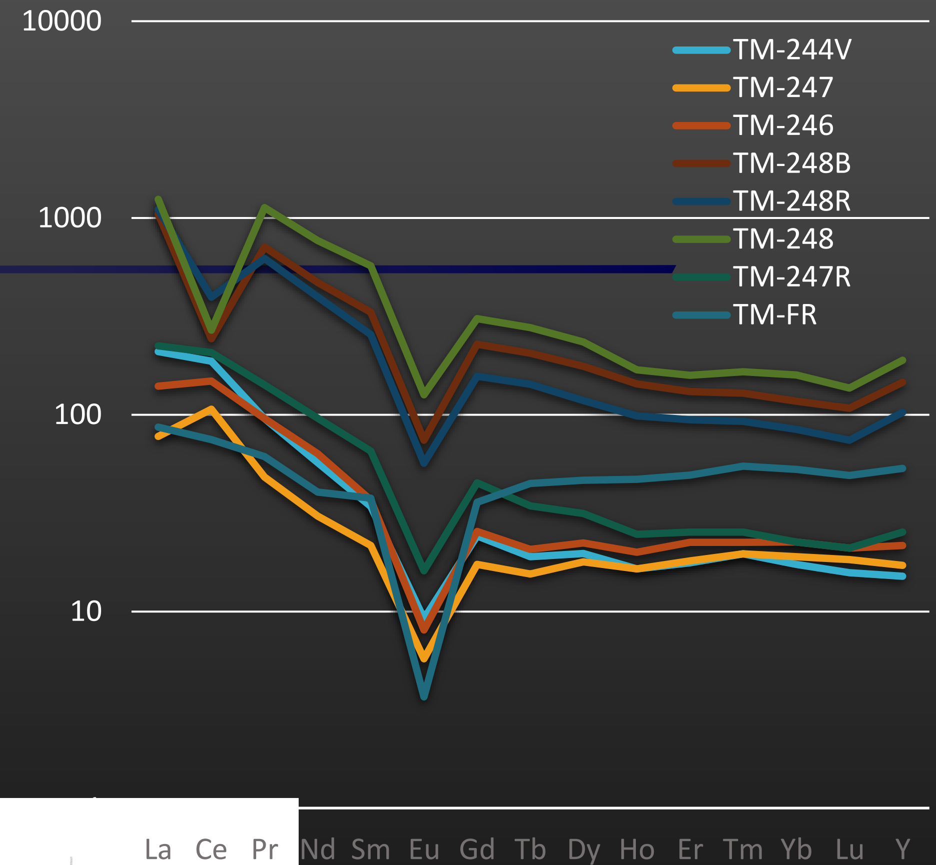
- Parent granite ASI = 1.94 peraluminous "S"-type granites.
- TRE grade of weathered granite ranges from 33 to 2470 ppm downward.
- TM-244 and TM-248 show negative Ce anomaly and enriched in REE.

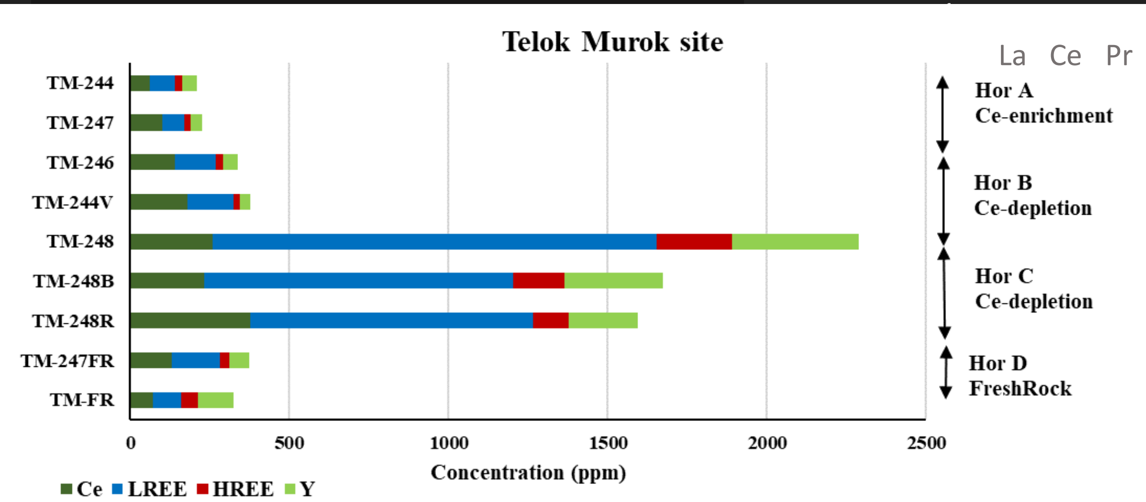


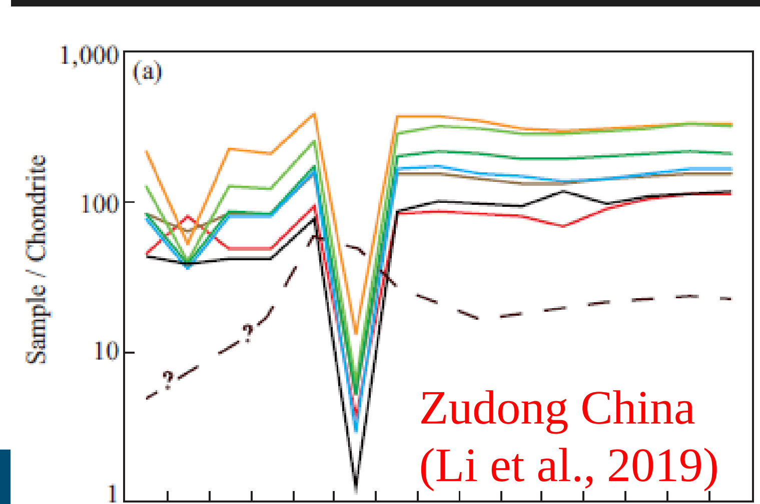
Composition / Element	TM-243	TM-244	TM-244V	TM-245	TM-246	TM-247	TM-247FR	TM-248
SiO_2	70.1536	70.3611	45.8424	94.5541	66.8314	67.5934	72.9287	68.1187
TiO_2	0.1799	0.5052	0.3455	0.0204	0.4357	0.3398	0.2593	0.4083
Al_2O_3	20.3416	19.83	34.5971	3.7613	22.6213	22.4613	14.7468	18.4072
FeO (Fe_2O_3)	2.7024	2.3182	3.2582	0.3035	3.257	2.6997	2.7506	1.3752
MnO	0.0176	0.0178	0.0266	0	0.0313	0.01	0.0507	0.0198
MgO	0.0267	0.0435	0.0412	0.0318	0.0662	0.0731	0.2138	0.1292
CaO	0.1381	0.032	0.1504	0.2253	0.2359	0.0182	1.6457	0.1119
Na_2O	0	0	0.012	0.017	0.011	0.0127	0.9558	0.2671
K_2O	0.2334	0.3769	0.4503	0.2838	0.638	0.9654	5.0041	4.5083
P_2O_5	0.0138	0.023	0.0502	0	0.0196	0.0163	0.1112	0.078
TOTAL (%)	99.9166	99.8671	99.8692	99.9858	99.8205	99.9014	99.8333	99.5861
LOI	6.02	6.32	15.02	0.78	5.59	5.66	1.15	6.15
ASI	54.76	48.50	56.47	7.15	25.56	22.54	1.94	3.77
CIA (%)	98	98	98	88	96	96	66	79
U	4.8	9.4	N.A.	N.A.	N.A.	N.A.	18.1	16
Th	46.2	48	N.A.	N.A.	N.A.	N.A.	56.5	55.2
La	22.2	30.7	76.8	6.4	51.3	28.5	82.1	626.8
Ce	48.6	61.5	178.8	12.9	142	102.1	198.2	360.3
Pr	5.3	7.9	13.1	1.7	13.1	6.6	19.4	217.2
Nd	17.3	26.4	40.6	5.9	45.1	21.7	68.2	679.9
Sm	3.8	6.3	7.9	1.5	8.5	5	15.1	166.5
Eu	0.4	0.5	0.8	0.3	0.7	0.5	1.4	13.5
Gd	3.3	6.4	7.4	1	7.8	5.3	13.8	129.7
Tb	0.5	1.2	1.1	0.1	1.2	0.9	2	21.5
Dy	3.6	8.8	7.5	1.5	8.5	6.8	12	115.8
Ho	0.6	1.8	1.4	0.2	1.7	1.4	2.1	19.3
Er	1.9	5.8	4.4	0.5	5.6	4.5	6.3	54.2
Tm	0.3	0.9	0.7	0.1	0.8	0.7	0.9	7.7
Yb	2	6	4.3	0.5	5.6	4.7	5.6	51.4
Lu	0.3	0.9	0.6	0.1	0.8	0.7	0.8	6.5
Y	15.8	45.7	31.7	4.4	45.4	36	53.1	560.8
Sc	31.3	30.2	30.3	36.9	37.9	28.2	29.3	33.4
LREE	97.6	133.3	318	28.7	260.7	164.4	384.4	2,064.2
HREE	12.5	31.8	27.4	4	32	25	43.5	406.1
REE	110.1	165.1	345.4	32.7	292.7	189.4	427.9	2,470.3
TRE+Y	125.9	210.8	377.1	37.1	338.1	225.4	481	3,031.1
LREE/HREE	7.81	4.19	11.61	7.17	8.14	6.57	8.84	5.08
Ce/Ce*	1.08	0.96	1.36	0.94	1.32	1.80	1.20	0.23
Eu/Eu*	0.34	0.24	0.32	0.74	0.26	0.29	0.29	0.28

Telok Murok Site

Chondrite-normalized REE diagram of weathered crust of granite and related parent rock from **Telok Murok** site (values of chondrite are from (Sun and McDonough, 2008)).







Thank you