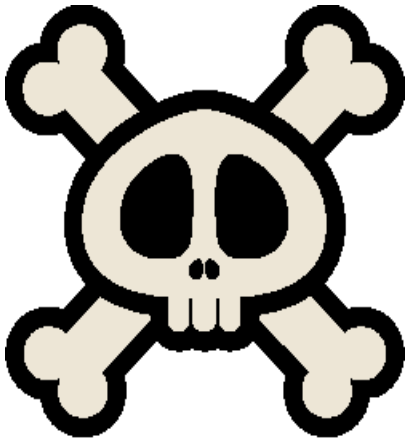
Relationship between main products and by-products.

Bad stories….



Harmful by-products

Arsenic (As)
Mercury (Hg)
Cadmium (Cd)

←by-product of copper (Cu) or zinc (Zn) or lead (Pb)

Uranium (U)
Thorium (Th)

←by-product of rare earth metals (REMs)

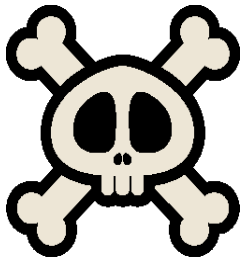
Leaf of radish

Root of radish

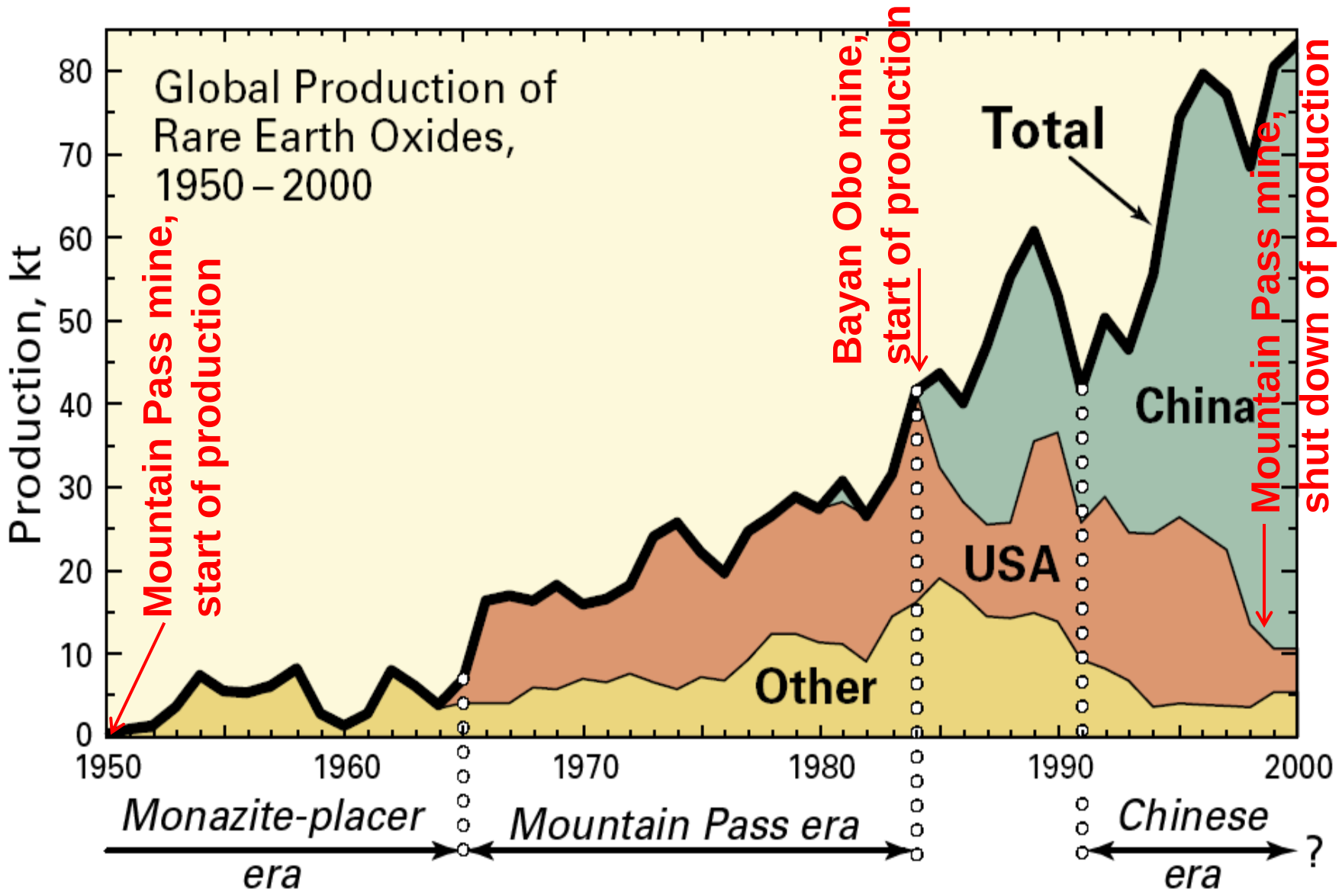
When producing metals from natural ore, harmful/toxic materials are also generated.

Majority of the harmful/toxic materials are treated at mining/smelting site.

Most of the people do not realize the real situation of waste treatment.



Transaction of rare earth ore production



G.B. Haxel, J.B. Hedrick, and G.J. Orrs, *USGS Fact Sheet,* 087-02, (2002).

Courtesy of Prof. Osamu Takeda / Tohoku University

Supply of REE

- Worlds' 97 % supply is dominated by China.

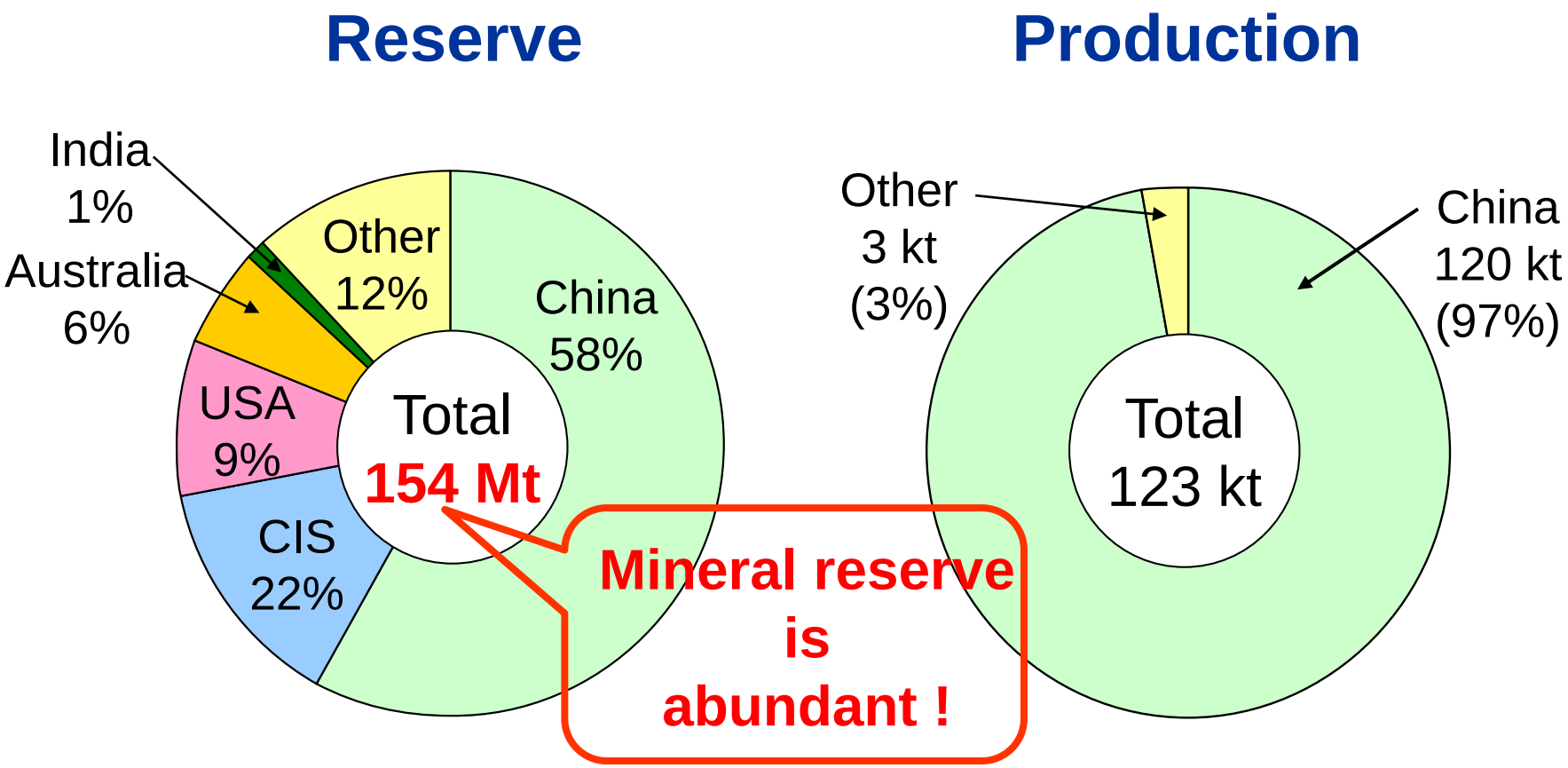


Fig. REE reserves in 2005.
(http://homepage3.nifty.com/bs3/Magnet/)

Fig. World share in supply of REE in 2006.
(USGS Mineral Commodity Summaries (2007))

Harmful by-products

Arsenic (As)
Mercury (Hg)
Cadmium (Cd)
←by-product of copper (Cu) or zinc (Zn) or lead (Pb)

Uranium (U)
Thorium (Th)
←by-product of rare earth metals (REMs)

Comparison of costs for producing metal and alloys of rare earth metals

	Japan	US	China	Australia
Feed cost	× high	× high	◎ very low	○ low
Energy cost	× high	○low	? low	○ low
Environmental cost	× very high	× high	◎ very low	× high
Employment cost	× high	× high	× low	× high

http://www.rootforce.org/2013/05/01/clean-and-green-rare-earth-elements-and-technology/

http://blogs.unimelb.edu.au/sciencecommunication/2013/09/08/whats-all-this-commotion-about-rare-earth-elements/

When googling "Baotou Tailing Dam" various images can be obtained

http://www.reuters.com/article/2010/11/21/us-climate-emissions-idUSTRE6AK1OU20101121

http://www.businessinsider.com.au/photos-of-chinese-rare-earth-mining-2013-4#china-accounts-for-about-97-percent-of-the-worlds-supply-of-rare-earths-1

Rare-earth mining in China comes at a heavy cost for local villages

Pollution is poisoning the farms and villages of the region that processes the precious minerals

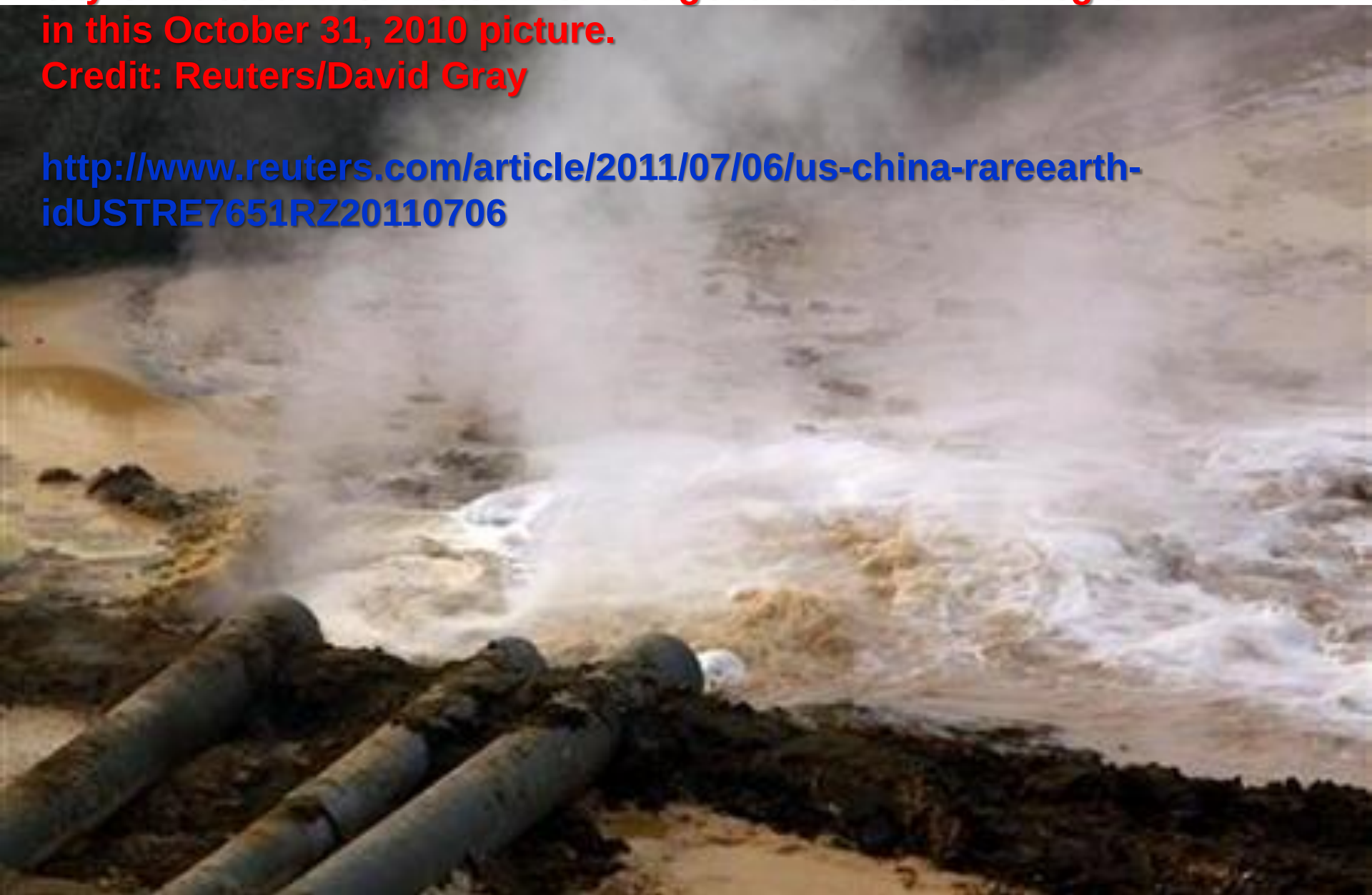
Guardian Weekly, Tuesday 7 August 2012 13.59 BST

Health hazard ... pipes coming from a rare-earth smelting plant spew into a tailings dam on the outskirts of Baotou in China's Inner Mongolia autonomous region. Photograph: David Gray/Reuters

http://www.theguardian.com/environment/2012/aug/07/china-rare-earth-village-pollution

Pipes coming from a rare earth smelting plant spew polluted water into a vast tailings dam near Xinguang Village, located on the outskirts of the city of Baotou in China's Inner Mongolia Autonomous Region in this October 31, 2010 picture.
Credit: Reuters/David Gray

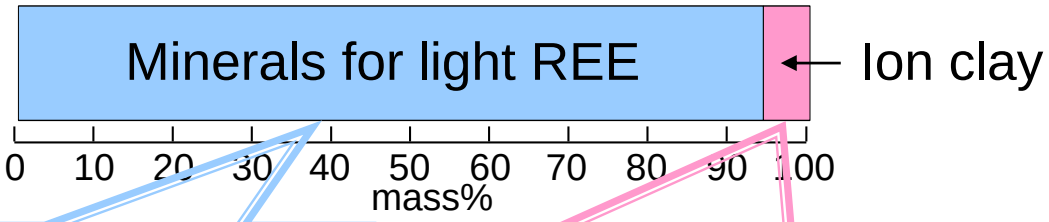
http://www.reuters.com/article/2011/07/06/us-china-rareearth-idUSTRE7651RZ20110706



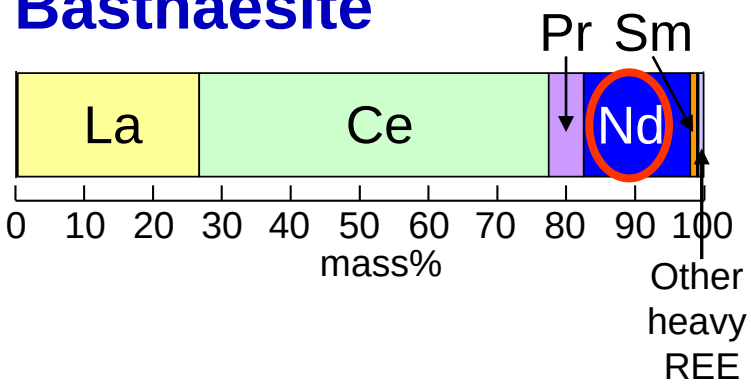
Mineral Resource for Nd and Dy

Ratio of production amount of Minerals for REE in China (oxide base)

Production of REE in 2006 (oxides) 120,000 t

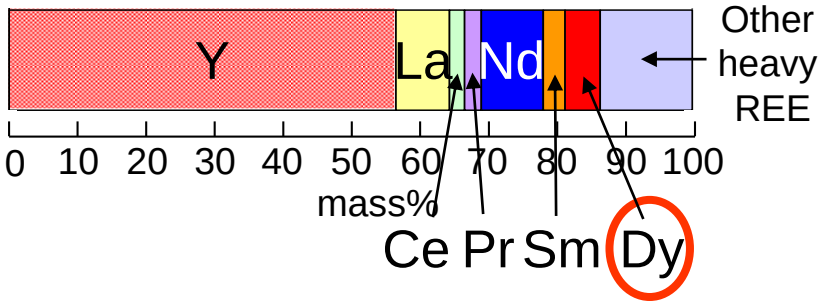


Bastnaesite



- ○ Rich in light REE (La, Ce, Pr, Nd)
- × Contain U and Th
- ○ Abundant all over the world

Ion adsorption ore (ion clay)



- ◎ Rich in heavy REE (Tb, Dy, Ho, Er, Tm, Yb)
- ○ No U and Th
- × Scarce and limited
- × Distributed only in China

(The Rare Metal News: Arum Ltd.)
(USGS Mineral Commodity Summaries (2007))

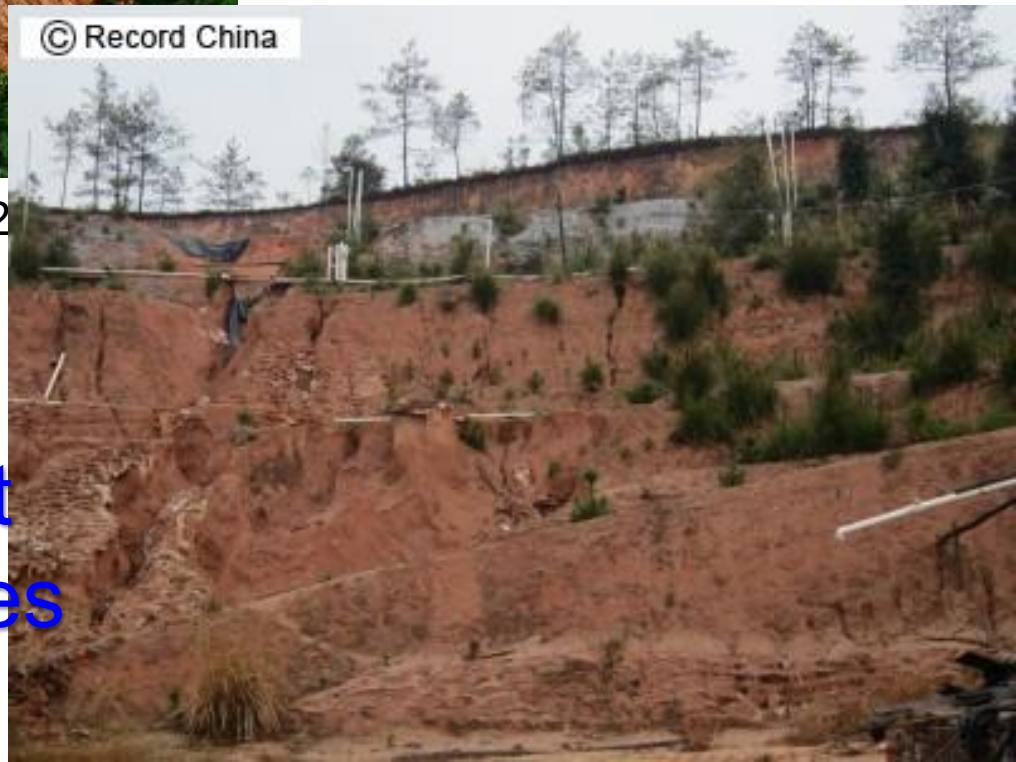
Current status of rare earth production in China and recycling in Japan

Institute of Industrial Science,
The University of Tokyo
Toru H. Okabe

'Current status of rare earth production in China and recycling in Japan',
Toru H. Okabe:
REE4EU Project
REE4EU Exploitation Workshop
Presentation in the exploitation workshop with external industry and EU-policy participation, Wednesday 24th April, (45 min)
[April 22-25, 2019, Stakeholders workshop, 24 April 2019, Avenue de la joyeuse Entrée 1, 4thfloor, 1040 Brussels, Belgium] (2019. 4. 24).
[Invited presentation]

http://www.asahi.com/business/intro/TKY201206030331.html

http://www.recordchina.co.jp/group.php?groupid=51816



When googling “rare earth environment pollution” various images can be obtained

Mining site of ion-absorption ore at Southern China

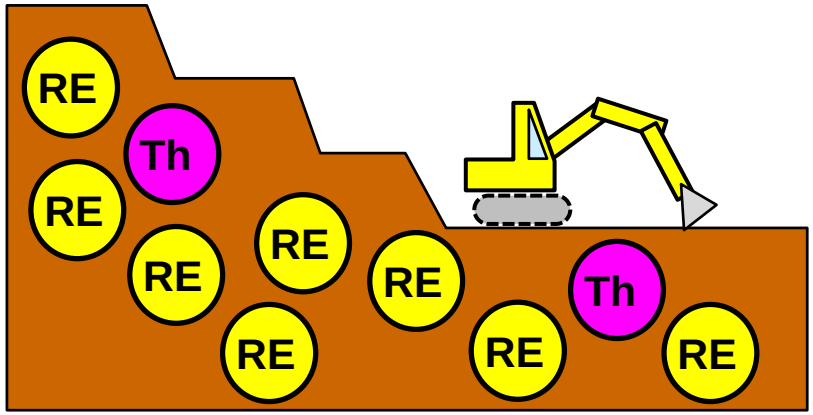
中国南部のイオン吸着型鉱山

Courtesy: Prof. A. Shibayama

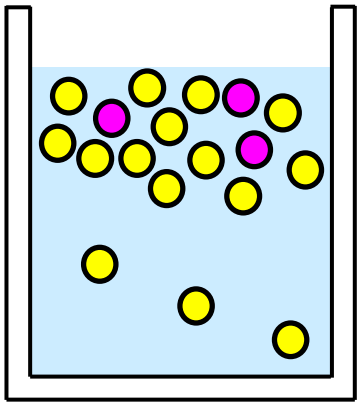
写真提供:
秋田大学大学院工学資源学研究科　柴山　敦　教授

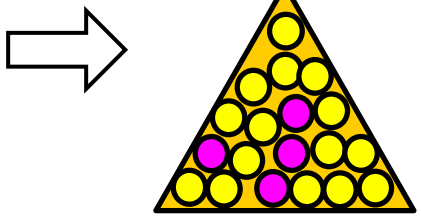
Mining methods of rare earth

Mining of rock type ore (Northern China)



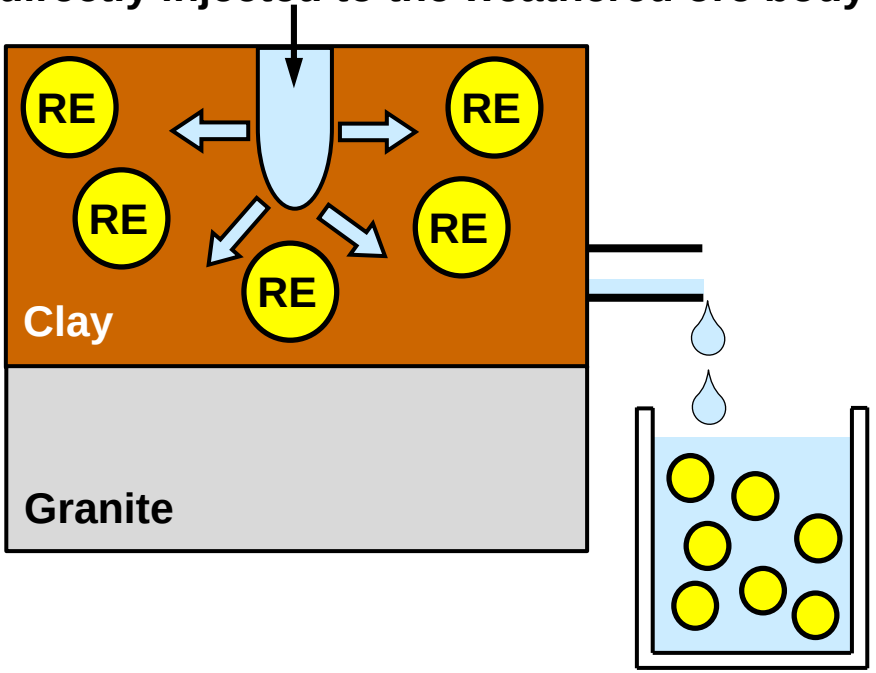
Mineral dressing

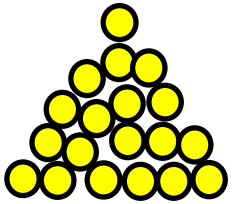




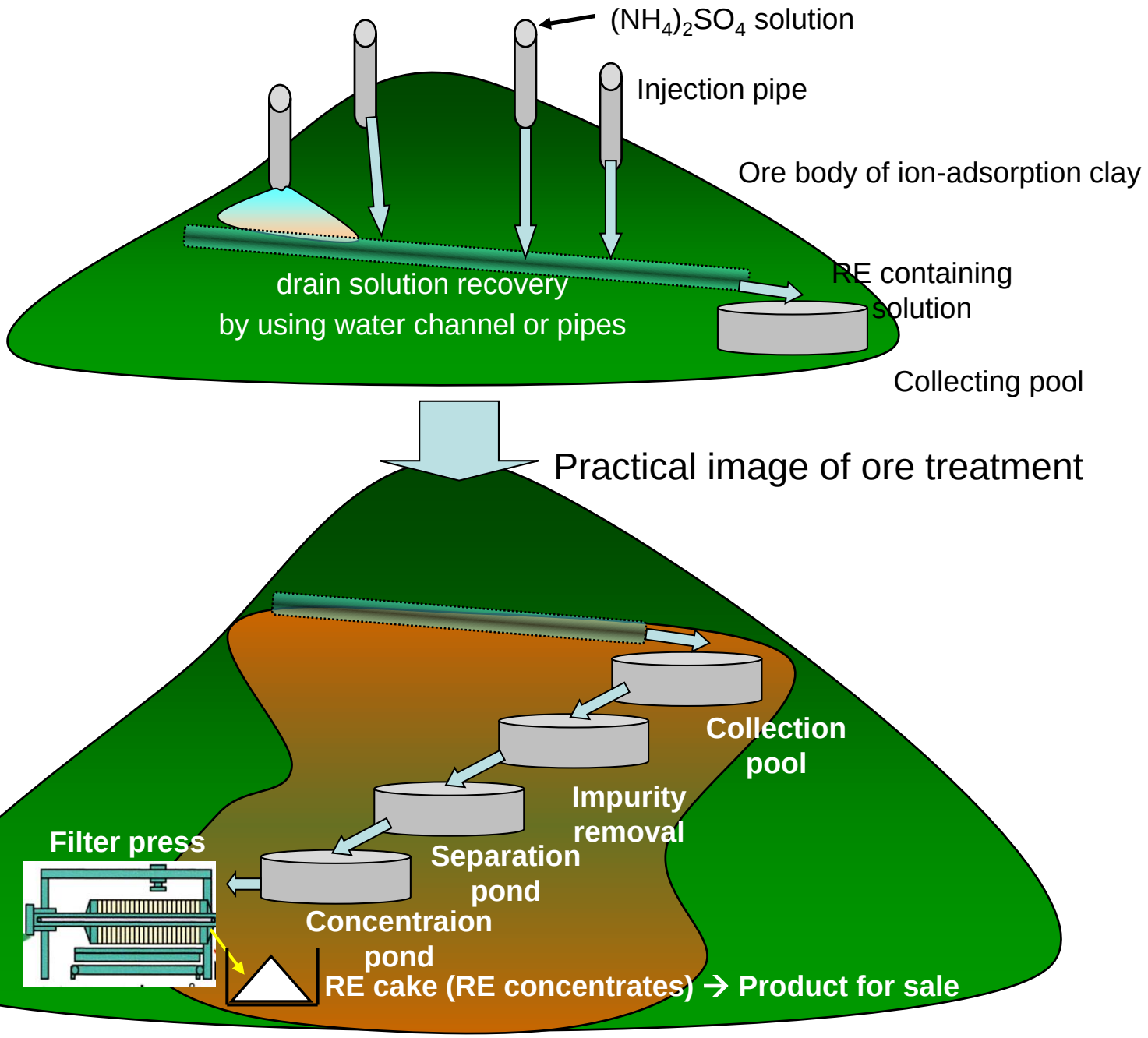
Mining of ion-absorption clay (Southern China)

Ammonium sulfate solution is directly injected to the weathered ore body





Rare earth compounds



写真提供:
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

写真提供：
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

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写真提供:
秋田大学大学院工学資源学研究科　柴山　敦　教授

ケーキ中のレアアース品位20～35%と極めて高く、溶媒抽出（一度浸出後）する原料となる。
ケーキの生産量が1区域（鉱山）のみで年間最低1,000トン

写真提供：
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

写真提供:
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

写真提供:
秋田大学大学院工学資源学研究科　柴山　敦　教授

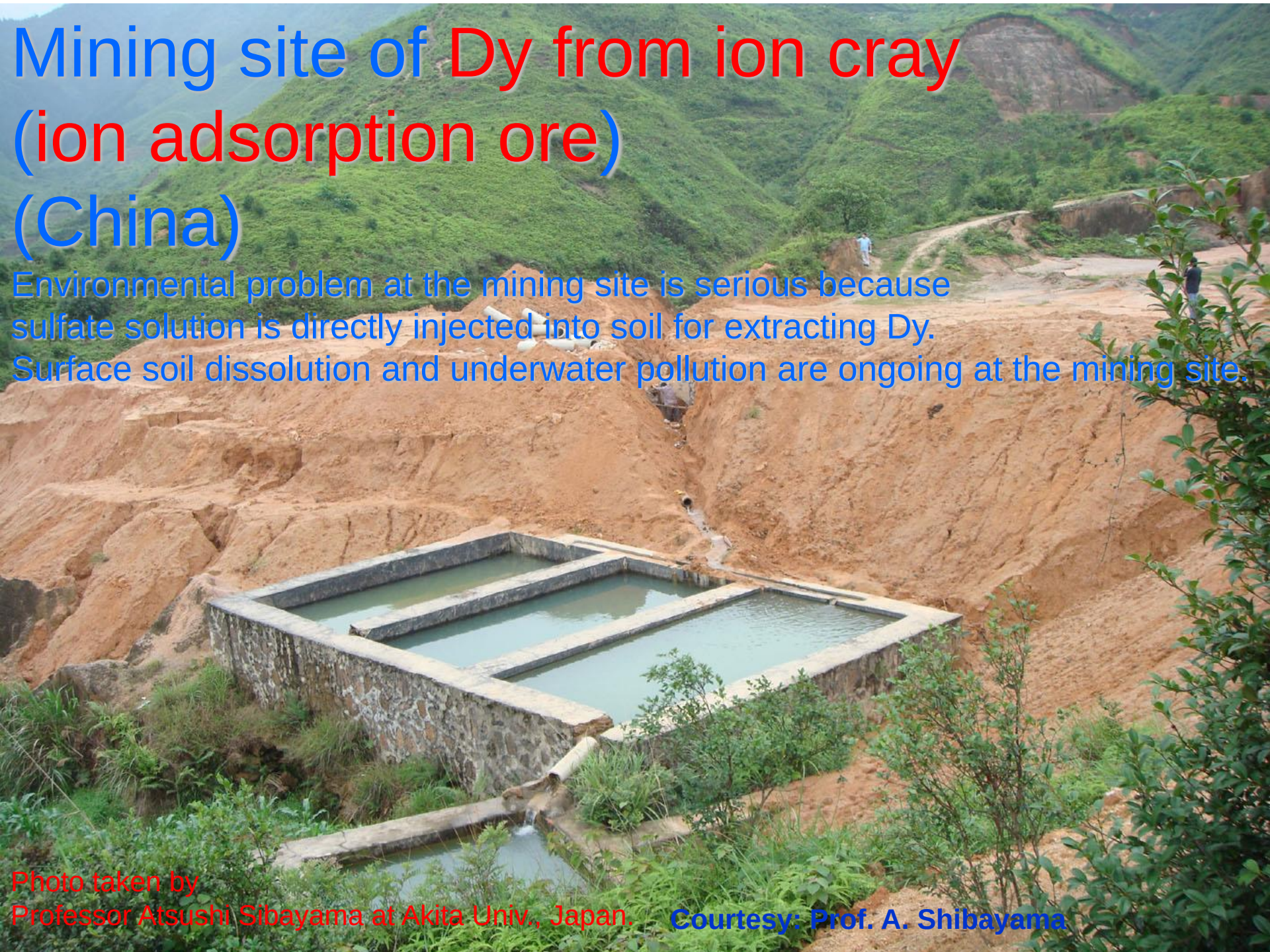
Courtesy: Prof. A. Shibayama

Environmental cost is NOT paid

写真提供：
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

Mining site of Dy from ion cray (ion adsorption ore) (China)



Environmental problem at the mining site is serious because sulfate solution is directly injected into soil for extracting Dy.
Surface soil dissolution and underwater pollution are ongoing at the mining site.

Photo taken by
Professor Atsushi Sibayama at Akita Univ., Japan.

Courtesy: Prof. A. Shibayama

Mining site of Dy from ion cray (China)

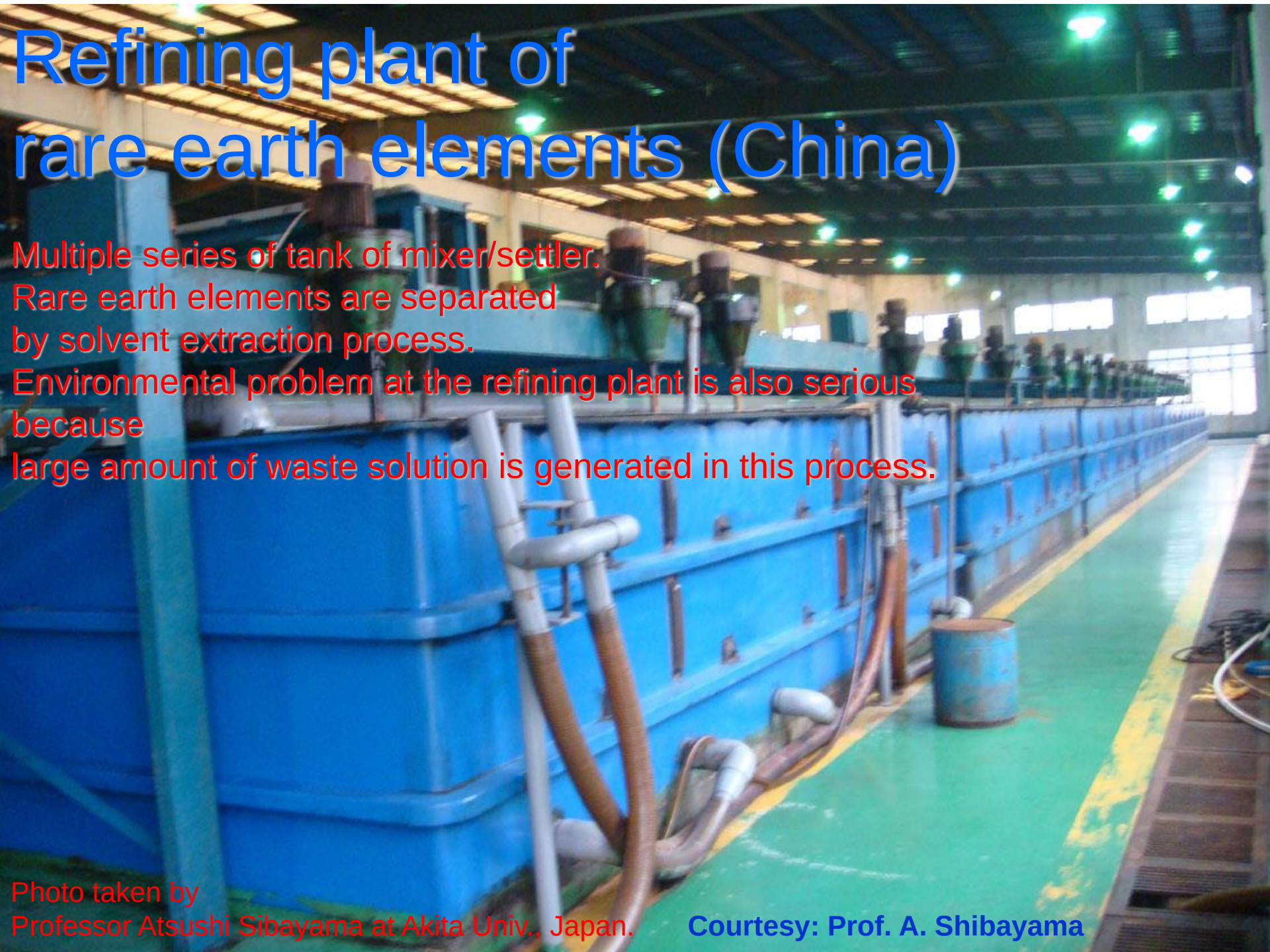
Refining plant of Dy obtained from ion cray (China)

Recovered Dy containing solutions are concentrated and refined at the plant.
Environmental problem at the refining plant is also serious because large amount of waste solution is generated.

Photo taken by
Professor Atsushi Sibayama at Akita Univ., Japan.

Courtesy: Prof. A. Shibayama

Refining plant of rare earth elements (China)



Multiple series of tank of mixer/settler.
Rare earth elements are separated
by solvent extraction process.
Environmental problem at the refining plant is also serious because
large amount of waste solution is generated in this process.

Photo taken by
Professor Atsushi Sibayama at Akita Univ., Japan.

Courtesy: Prof. A. Shibayama

写真提供：
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

南方鉱の処理工程

沈殿分離工程

イットリウム専用ライン

写真提供:
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

廃水処理工程

写真提供:
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

写真提供:
秋田大学大学院工学資源学研究科　柴山　敦　教授

Courtesy: Prof. A. Shibayama

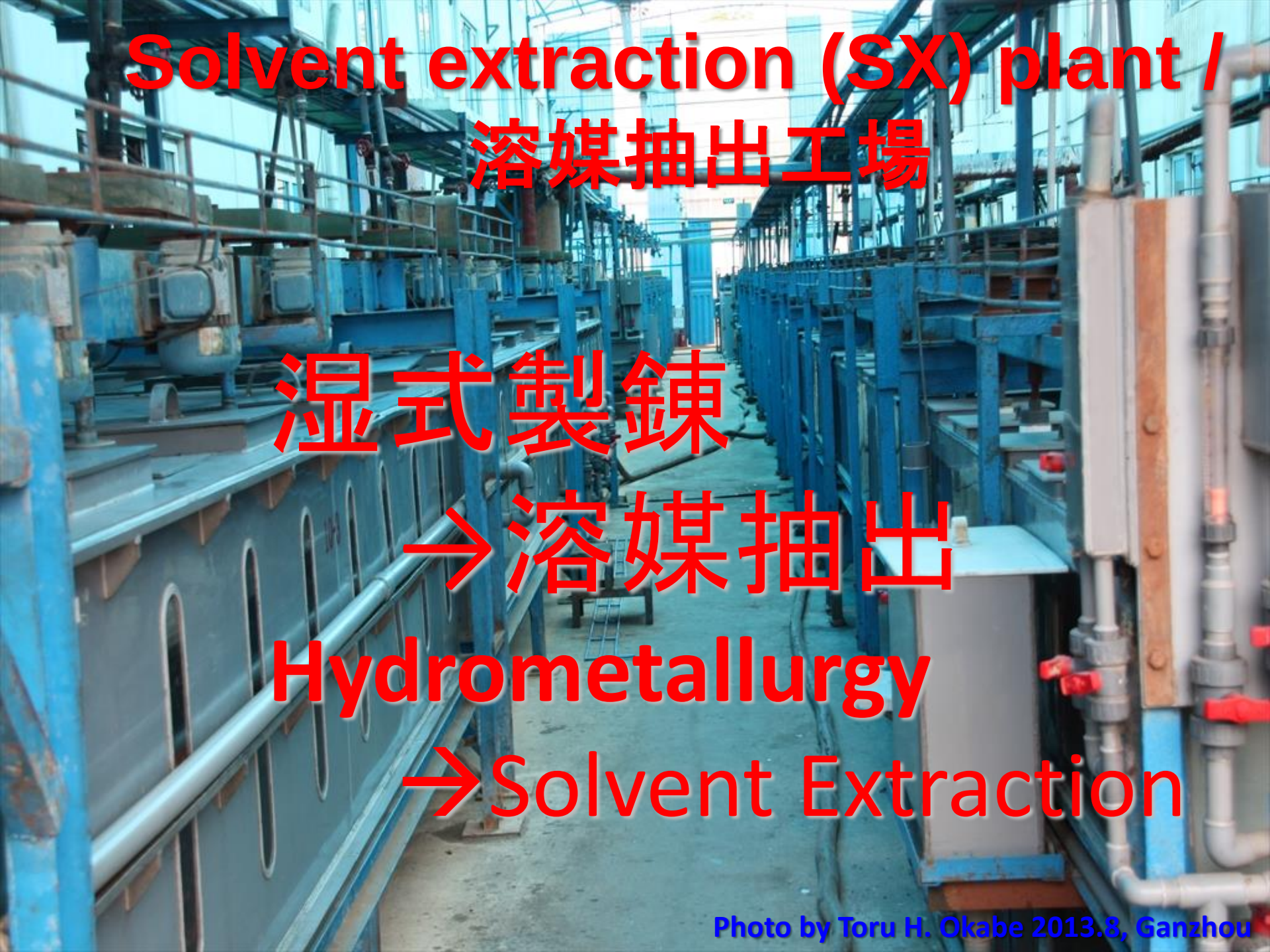
Bottleneck of rare earth:

In Augut, 2013,
Visited to Ganzhou city at
Southern Jiangxi province,
famous for Ion Cray

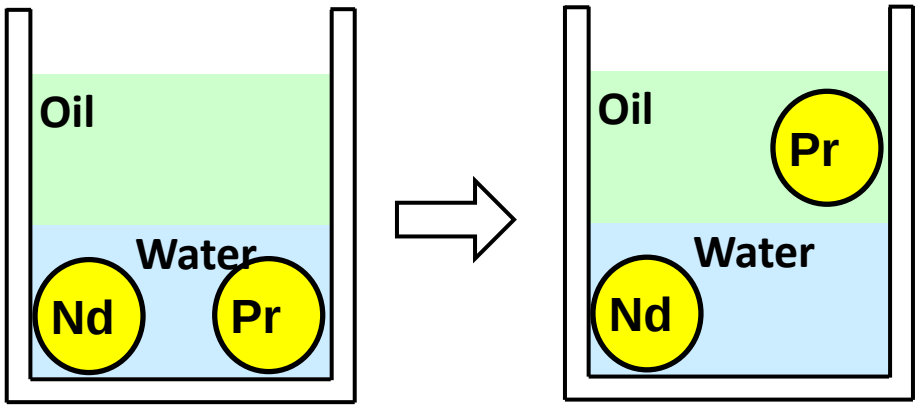
レアアース生産のボトルネック
2013年8月、
中国南部、
江西省のGanzhouという、
イオン吸着鉱で有名な
地域の視察報告

Forbidden zone

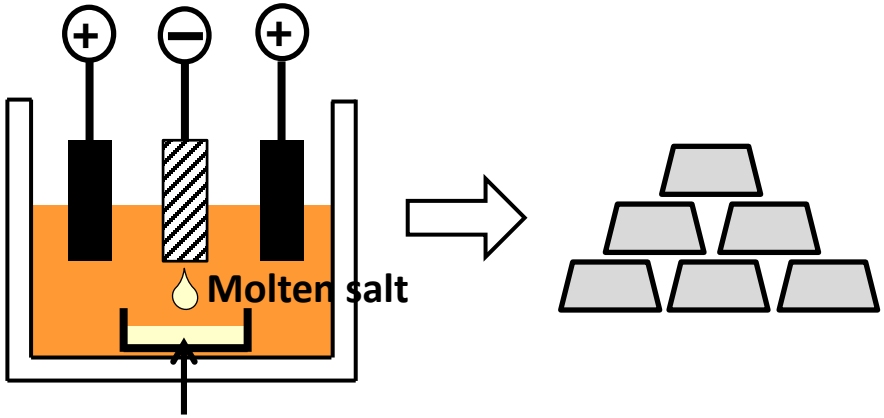
部外者の
立ち入りは
禁止されている


Solvent extraction (SX) plant /
溶媒抽出工場
湿式製錬
→溶媒抽出
Hydrometallurgy
→Solvent Extraction
Photo by Toru H. Okabe 2013.8, Ganzhou

Separation / purification of rare earth



Metal production by molten salt electrolysis



Molten RE metal or alloy

RE metal/alloy ingot

東北大学大学院　工学研究科金属フロンティア工学専攻　竹田　修　博士　作成

参考）足立吟也編：「希土類の機能と応用」，CMC出版(2006); 足立吟也編：「希土類の材料技術ハンドブック」，NTS (2008); JOGMEC NEWS, Vol. 27 (2011)


Pyrometallurgical refining
→ Molten salt electrolysis
乾式製錬
→溶融塩電解
Photo by Toru H. Okabe 2013.8, Ganzhou

Table 2

Overview of rare earth elements (REE) market (2013) (Unit: REO t)[9]. Supply source of REE is expanded, but supply source of Dy is still limited in China.

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy
China (north & south)	28492	40622	6352	19374	2762	389	1946	250	1247
Australia Lynas	255	467	53	185	23	4	8	1	1
USA Molycorp	1328	1964	174	480	32	4	7	1	1
Russia Lovozerskiy	521	1081	101	265	20	3	4	-	-

Industrial Rare Metals, Annual Review 2014, Arumu Publ. Co.

RE alloy production plant (China)

Rare earth metals and alloys are produced by molten salt electrolysis.

Feed material: RE oxides.

Molten salt: Fluoride salt.

Cell: 3 kA

Product: Nd, or Dy alloys

Courtesy of Dr. Eiji Nakamura (Santoku Co. Ltd.)

RE alloy production plant (China)

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Feed material: RE oxides.

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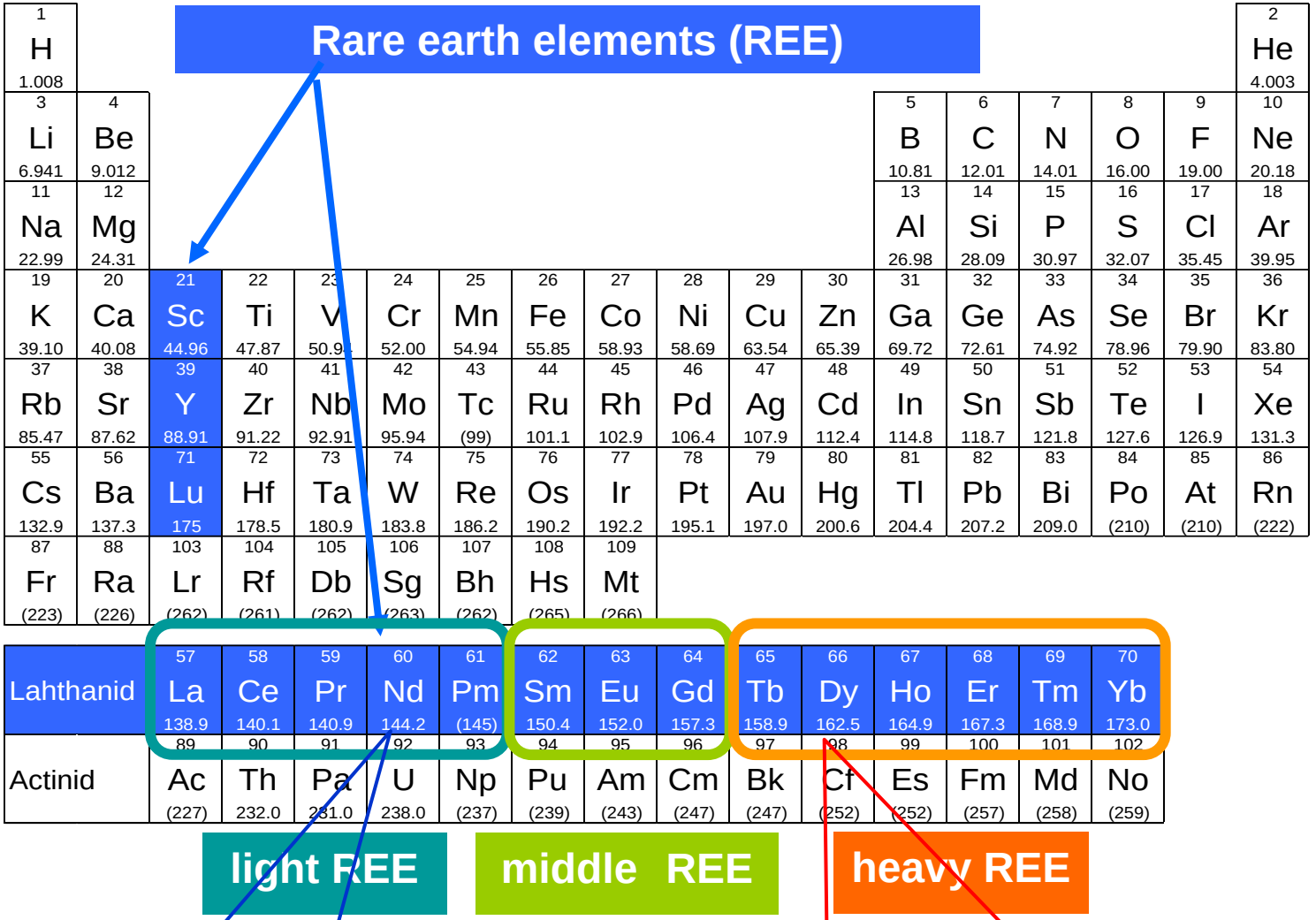
Courtesy of Dr. Eiji Nakamura (Santoku Co. Ltd.)

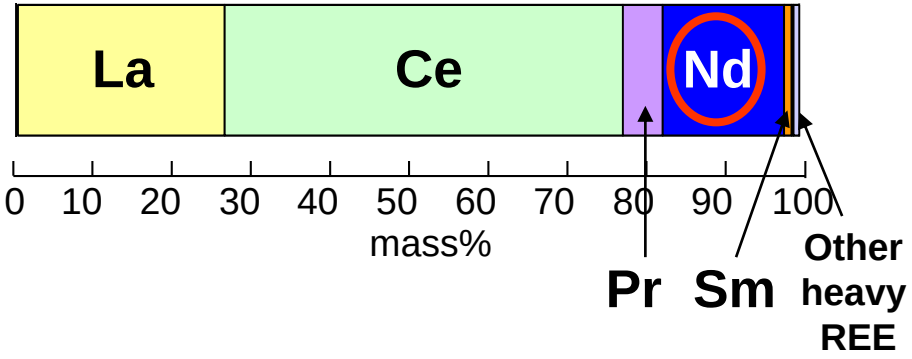
Rare Earth Elements ?



Resource for Nd and Dy

Rare earth deposits

Bastnaesite

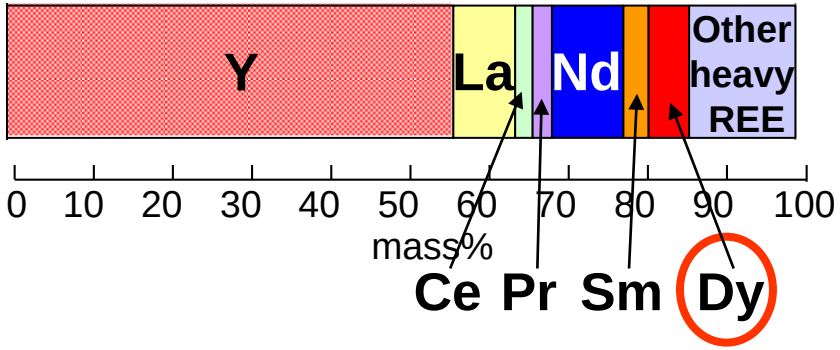


Nd: 1~2 mass% U : 8.7×10^{-4} mass%

Dy: trace Th: 0.14 mass%

- ○ Rich in light REE (La, Ce, Pr, Nd)
- × Contain U and Th
- ○ Abundant all over the world

Ion adsorption ore (ion clay)



Nd: 70~200 ppm U : –

Dy: 40~120 ppm Th: –

- ○ Rich in heavy REE (Tb, Dy, Ho, Er, Tm, Yb)
- ○ Less radio active element
- × Scarce and limited
- × Distributed only in China


Bayan Obo Mining District
白雲鄂博礦區
A mining town in the west of Inner Mongolia, People's Republic of China
包頭市
A
Ulaanbaatar
Улаанбаатар
Mongolia
Inner Mongolia
Heilongjiang
Harbin
哈尔滨
Changchun
长春
Jilin
Shenyang
沈阳
Liaoning
Vladivo
Beijing
北京
Hebei
Tianjin
天津
North Korea
Pyongyang
평양
Seoul
서울
Gansu
Ningxia
Shanxi
Jinan
济南
Shaanxi
Shandong
South Korea
Qinghai
China
Xi'an
西安
Zhengzhou
郑州
Gwangju
광주
Busan
부산
Hiro
Henan
Fukuoka
福岡
Jiangsu
Shanghai
上海
Chengdu
成都
Hubei
Wuhan
武汉
Anhui
Kagoshima
鹿児島
Sichuan
Chongqing
重庆
Hangzhou
杭州
East China Sea

The largest Bayan Obo Mine (China)

Rare earth ore produced from this mine contains naturally occurring radioactive materials(NORM) such as thorium (Th) and uranium (U)

図1（a） 中国・内モンゴル自治区のバイヤンオボ鉱床．中国の内蒙古自治区に位置するバイヤンオボ鉱床の露天採掘場。バイヤンオボ鉱床は、主に鉄を採掘している鉱床であり、レアアースは副産物として生産されている。この鉱床は、La，Ce，Ndなどの軽希土に富む鉱床である。レアアース生産量及び埋蔵鉱量ともに世界最大で、現在もこの鉱床が世界のレアアース生産を牽引している．（産業総合技術研究所 村上浩康主任研究員撮影・提供，2005年8月撮影）


Bayan Obo Mining District
白雲鄂博礦區
From Baotou City,
more than 120 kilometres
(75 mi) to the north
包頭市 / Baotou city
Xilin Gol
錫林郭勒盟
Ulanqab
乌兰察布市
Hohhot
呼和浩特市
Zhangjiakou
张家口市
Baotou
包头市
Datong
大同市
Beijing
北京市
Langfang
廊坊市
Ordos
鄂尔多斯市
Shuozhou
朔州市

Bayan Obo Mining District
白雲鄂博礦區

Bayan Obo Mining District 白雲鄂博礦區

http://en.wikipedia.org/wiki/Bayan_Obo_Mining_District


In the Inner Mongolia Autonomous Region, there are many mining sites.
内モンゴル自治区Baotou 周辺には多数の鉱山が存在する
Photo by Toru H. Okabe 2014.7, Baotou


Near Baotou city,
Inner Mongolia Autonomous Region
内モンゴル自治区Baotou (包頭市) 周辺
Photo by Toru H. Okabe 2014.7, Baotou


Baotou city,
Inner Mongolia Autonomous Region
内モンゴル自治区Baotou (包頭市)
Photo by Toru H. Okabe 2014.7, Baotou

On the way to
the world's biggest
rare earth mine,
we drove in a very "remote area"

レアアースの
世界最大の鉱山に行く
道中は
中国のなかでも
かなり田舎でした。。。。

Outer city of Baotou city, Inner Mongolia Autonomous Region

内モンゴル自治区
Baotou (包頭市) 郊外

Photo by Toru H. Okabe 2014.7, Baotou

Photo by Toru H. Okabe 2014.7, Baotou


Heading to north from Baotou city,
Inner Mongolia Autonomous Region
内モンゴル自治区
Baotou (包頭市)から北に移動
Photo by Toru H. Okabe 2014.7, Baotou


Photo by Toru H. Okabe 2014.7, Baotou


Photo by Toru H. Okabe 2014.7, Baotou

Many cows and sheep…

Photo by Toru H. Okabe 2014.7, Baotou

牛や羊が沢山いる


Very low populations…
人口密度は極めて低い
Photo by Toru H. Okabe 2014.7, Baotou


Photo by Toru H. Okabe 2014.7, Baotou

Photo by Toru H. Okabe 2014.7, Baotou