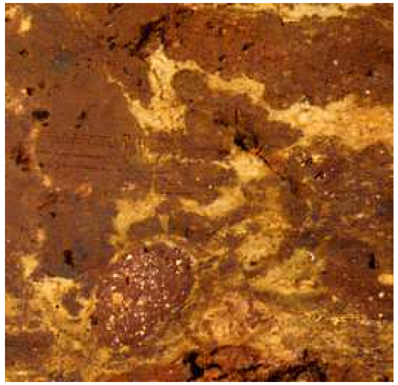

Bauxiti

Bauxite deposits are formed chiefly by weathering of aluminous rock; some have been transported to their present locations, but most are residual accumulations from which most other constituents of the parent rock, other than alumina, have been leached.

Bauxite deposits occur in rocks ranging in age from Precambrian to Holocene.



Gibbsitic bauxite: Most deposits of this type are in the tropics and a few occur in the temperate belts, but the climate was probably tropical or subtropical at the time these formed. Nearly all are of Cenozoic age.

Boehmitic bauxite: Deposits of this type occur chiefly in southern Europe, the USSR and Turkey. Most are associated with carbonate rocks of Jurassic and Cretaceous age, but a few are of Paleozoic age. Today most are north of the tropics, however they could have formed under tropical conditions.

Mixed bauxites are associated with both the gibbsite and boehmite types. However, they tend to be more abundant in deposits of Paleozoic and Mesozoic ages than in younger rocks.

Formazione delle bauxiti

The processes involved in bauxite formation are more complex than shown below, but the following example for weathering of feldspar is indicative of the overall net formation sequence.

Step 1: Acidification of rainwater

$CO_2 + H_2O \rightarrow H_2CO_3$

$H_2CO_3 \rightarrow HCO_3^- + H^+$

$HCO_3^- \rightarrow CO_2^- + H^+$

Step 2: Carbonic and humic acids (from soil) react with feldspar, leaching potassium and silica, and hydrating the alumino-silicate structure to form an illite clay:

$3KAlSi_3O_8 + 2H^+ + 12H_2O \rightarrow KAl_3Si_3O_{10}(OH)_2 + 2K^+ + 6Si(OH)_4$

Step 3: Further leaching removes the remaining potassium, transforming illite to kaolinite:

$2\ KAl_3Si_3O_{10}(OH)_2 + 2H^+ + 3H_2O \rightarrow 3Al_2Si_2O_5(OH)_4 + 2K^+$

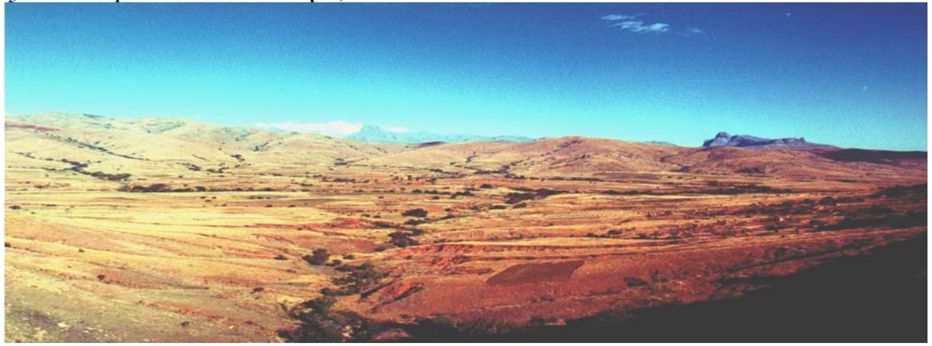
Step 4: Kaolinite is decomposed to form insoluble gibbsite and soluble hydrated silica:

$Al_2Si_2O_5(OH)_4 + 5H_2O \rightarrow 2Al(OH)_3 + 2Si(OH)_4$

Iron in the minerals is converted to the insoluble forms hematite and goethite. Titanium is transformed to anatase. Quartz and zircon are resistant to weathering.

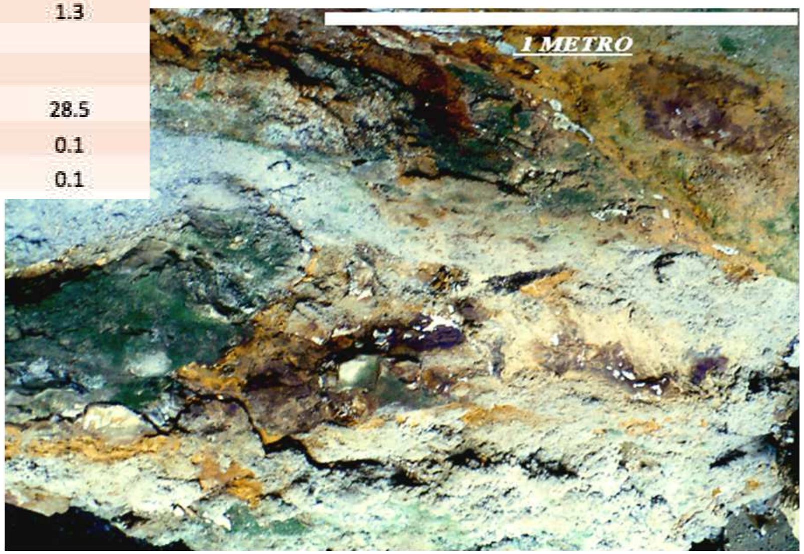
The mixture of remnant minerals is called 'laterite' and is a common surface feature in tropical areas. If it is sufficiently high in alumina and low in silica, it is characterized as 'bauxite'. Laterite bauxites account for most of the world's major deposits of bauxite.

Weathering of limestone gives rise to eroded surface and sub-surface features (caves & depressions) which are together known as '**karst**'. If the voids are subsequently filled with minerals containing aluminium (eg. clays or laterite) then further weathering may occur leading to bauxitisation. The resulting deposits are known as **karst bauxite**. They are important in Europe, China and Jamaica.



Caratteristiche chimiche/mineralogiche accessorie delle bauxiti

		Bauxite				
		Greek	Weipa, Australia	Trombetas, Brazil	Bintan, Indonesia	Gujarat, India
Al_2O_3 % in	Gibbsite	2.9	38.7	51.6	44.5	46.4
	Boehmite	24.6	11.1		0.7	2.0
	Diaspore	24.5	0.6			
	Kaolinite	2.3	4.3	2.8	3.5	0.9
	Other	1.6	0.3	0.6	1.9	1.6
	Total	55.9	55.0	55.0	50.6	50.9
SiO_2 % in	Quartz		1.1	0.1	2.0	0.1
	Kaolinite	2.3	5.1	3.3	4.1	1.2
	Other	1.2			0.5	-
	Total	3.5	6.2	3.4	6.6	1.3
Fe_2O_3 % in	Goethite	3.4	1.9	4.0	6.7	7.5
	Hematite	15.3	9.0	7.0	7.0	7.0
	Other	2.3				
	Total	21.0	10.9	11.0	13.7	14.5
TiO_2 % in	Anatase	1.8	2.0	1.0	1.0	3.0
	Rutile	0.9	0.5	0.2	0.2	0.3
	Total	2.7	2.5	1.2	1.2	3.3
CaO % in	Calcite	1.9				1.2
	Crandallite				0.5	0.1
	Total	1.9	0.1	0.1	0.1	1.3
MgO % in	Chamosite	0.1				
	Total	0.1	0.1			
LOI		13.1	13.6	28.9	27.3	28.5
C organic %		n.a.	0.2	0.0	0.1	0.1
P_2O_5 %		n.a.	0.1	0.0	0.1	0.1



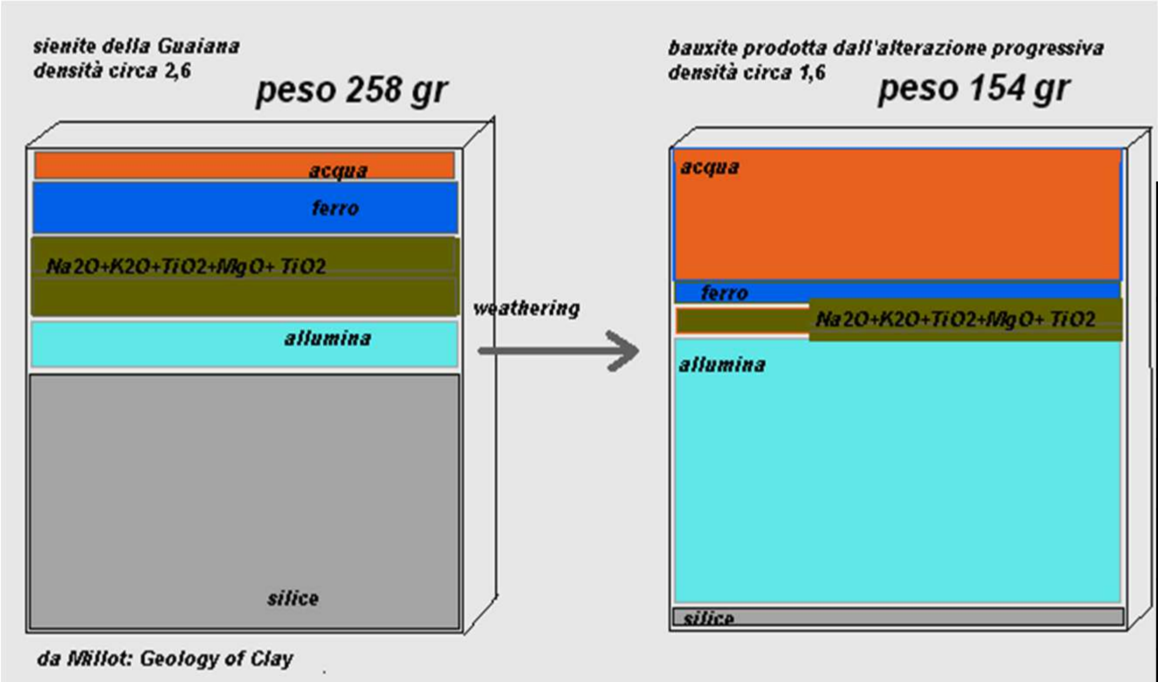
Bauxite reserves

Nation	2011	Percentage of Total	Cumulative Percentage
Guinea	7,400	27	27
Australia	6,000	22	48
Brazil	2,600	9	58
Vietnam	2,100	8	65
Jamaica	2,000	7	72
Indonesia	1,000	4	76
India	900	3	79
Guyana	850	3	82
China	830	3	85
Greece	600	2	87
Suriname	580	2	91
Venezuela	320	1	91
Russia	200	1	91
Sierra Leone	180	1	92
Kazakhstan	160	1	92
Others	2,120	8	100
World Total	27,820	100	

The top 5 countries, Guinea, Australia, Brazil, Vietnam and Jamaica, hold over 70% of the world's documented bauxite reserves.
Of these counties only Australia, Brazil and Jamaica have realized their potential as bauxite mining or alumina producing nations. While still a major bauxite producer sovereign risk has stunted development of the industry in Guinea to a fraction of its full potential.
Strict nationalistic policies in Vietnam have resulted in the industry only just beginning to emerge. Indonesia also possesses significant bauxite holdings and has become a major exporter to China.

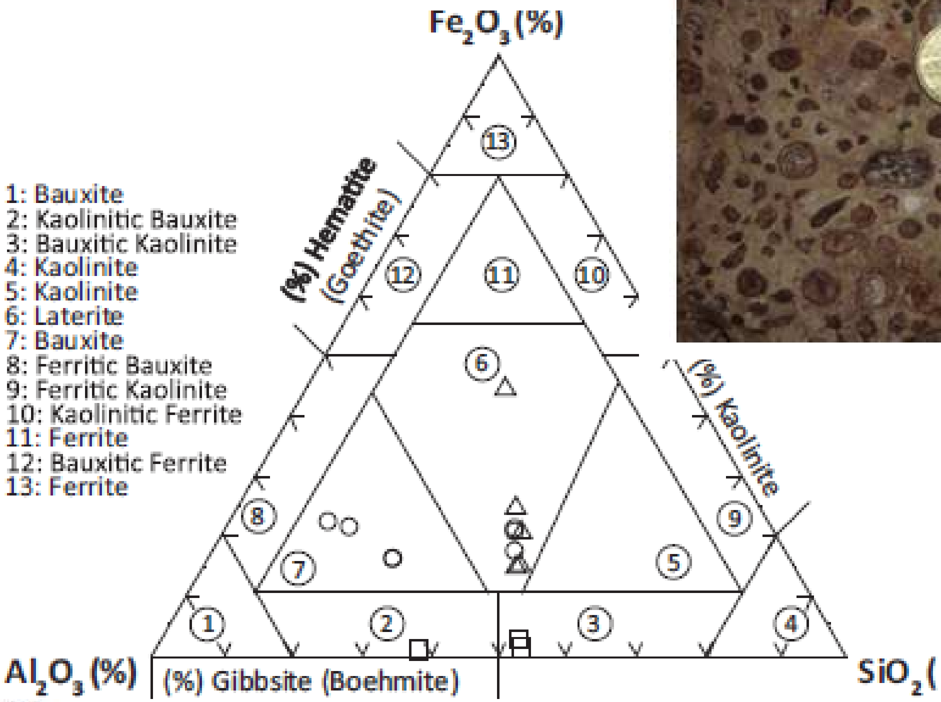
World Bauxite Reserves – Key Counties
Guinea: High alumina content. Major concentration areas: Lower Kindiaand Boke (around 5 billion),Central Labe (500 million), Gaoual(500 million); and Upper Dabola(around 1.9 billion).
Australia: Abundant reserves of easily mined surface deposits. Major concentration areas include: 1) the Gulf of Carpentaria, 2) Darling Ranges, 3) Mitchell Plateau and Cape Bougainville.
Brazil: 90% of Brazil's bauxite is distributed in Para State in northern Brazil.
Vietnam: Mainly distributed in DakLak, DakNong, Kon Tum and Lam Dong provinces in central and southern Vietnam. Deposits are mainly lateritic (Al_2O_3 36-39% or sedimentary (Al_2O_3 39-65%).
India: Widely distributed, however 60% of all identified reserves are in Orissa and Andhra Pradesh along East Coast.
Indonesia: Mainly distributed in Bangka Island, Belitung Island, West Kalimantan and Riau Province (Bintan Island).

Un esempio di formazione di bauxiti derivate dall'alterazione di sieniti e duniti: le bauxiti della Guinea (Isole Los Islands-Africa).



Composti in peso %	Roccia fresca	Roccia alterata
SiO2	57	3,1
Al2O3	17,5	56
Fe	4,6	5,6
CaO	2,6	0,2
MgO	1,1	-
Na2O	6	-
K2O	7	-
TiO2	0,7	2
MnO2	1	0,1
H2O	1,3	29

Definizioni delle rocce bauxitiche



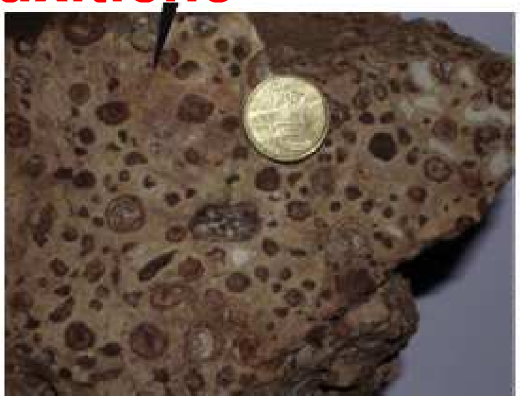
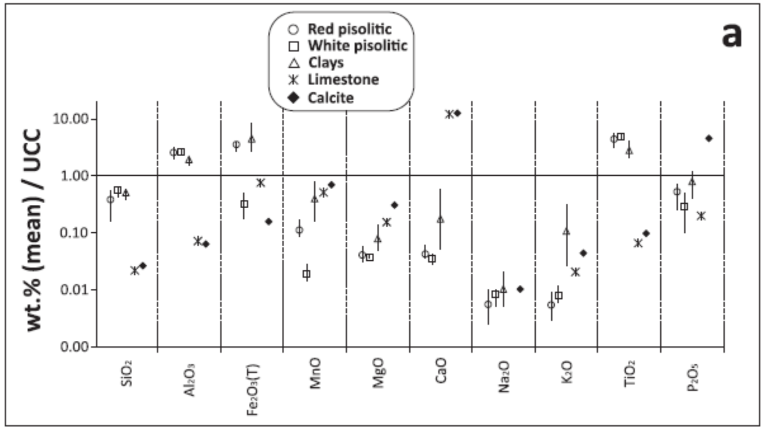
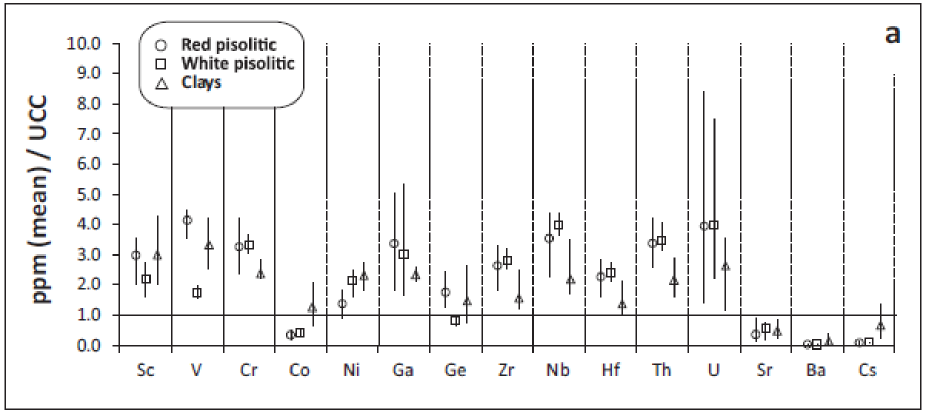
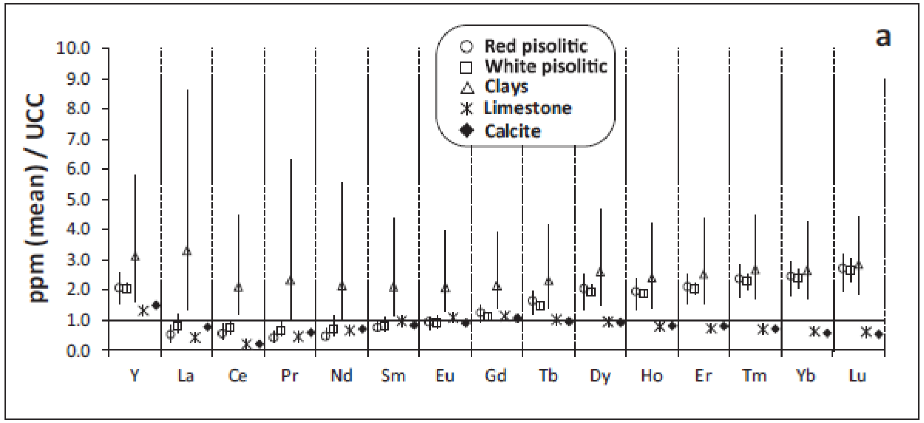


Table 1
Mineralogical composition (%) of the study samples (min.: minimum; max.: maximum; st. dv.: standard deviation). Kln: kaolinite; Gbs: gibbsite; Gt: goethite; Hem: hematite, Dsp: diaspore; Bhm: boehmite; Ant: anatase; Rt: ruitle; Ill: illite; Qtz: quartz; Cal: calcite; tr: traces.

		Whole sample											<2 µm fraction	
Sample description		Kln	Gbs	Gt	Hem	Dsp	Bhm	Ant	Rt	Ill	Qtz	Cal	Ill	Kln
Red pisolitic (n = 6)	mean	55	22	3	10	6	tr.	tr.	tr.	–	tr.	–	tr.	100
	min.	28	0	0	8	5								100
	max.	83	45	7	12	8								100
	st. dv.	22	22	3	1	1								0
White pisolitic (n = 3)	mean	78	10	2	–	6	tr.	tr.	tr.	–	–	–	tr.	100
	min.	57	0	0		5								100
	max.	92	31	5		7								100
	st. dv.	15	15	2		1								0
Clays (n = 5)	mean	66	–	12	7	4	–	tr.	tr.	4	tr.	1	11	89
	min.	44		0	0	0				0		0	0	60
	max.	79		25	18	9				18		5	40	100
	st. dv.	13		9	7	4				7		2	16	16


a
Red pisolitic
White pisolitic
Clays
Limestone
Calcite
wt.% (mean) / UCC
10.00
1.00
0.10
0.01
0.00
SiO2
Al2O3
Fe2O3(T)
MnO
MgO
CaO
Na2O
K2O
TiO2
P2O5


a
Red pisolitic
White pisolitic
Clays
ppm (mean) / UCC
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Sc
V
Cr
Co
Ni
Ga
Ge
Zr
Nb
Hf
Th
U
Sr
Ba
Cs


a
Red pisolitic
White pisolitic
Clays
Limestone
Calcite
ppm (mean) / UCC
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Y
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu

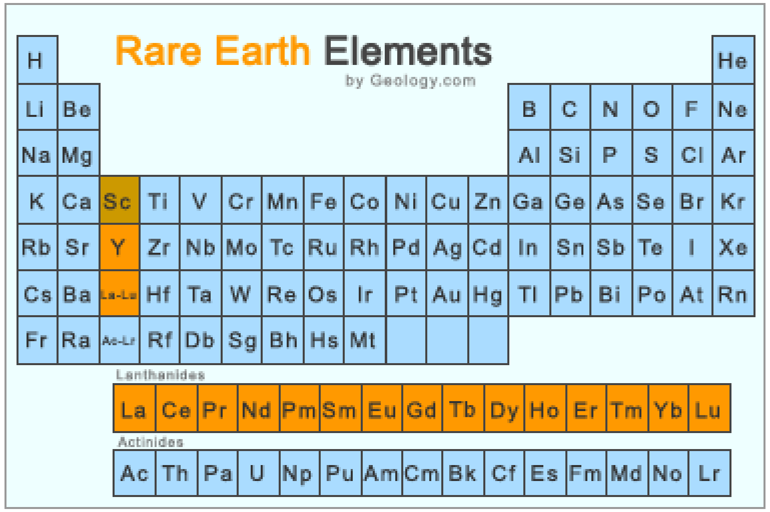
E’ necessario un clima tropicale o subtropicale, alte temperature, forti precipitazioni alternate a siccità.

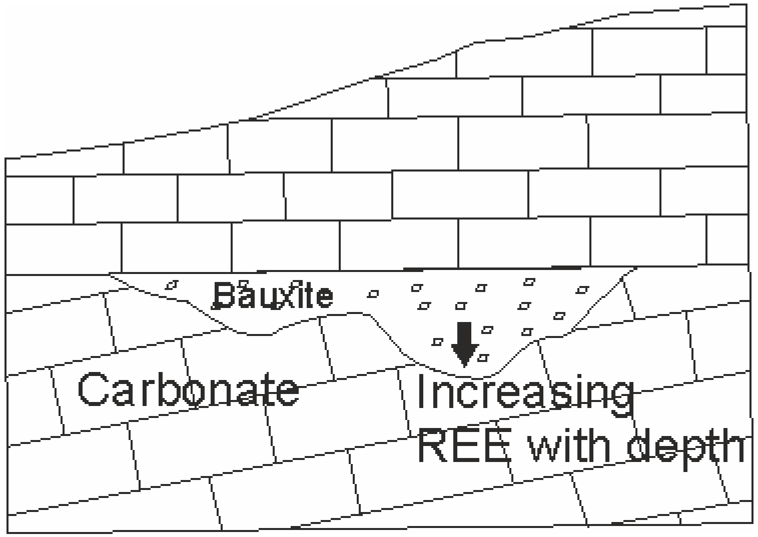
La collocazione è generalmente in terreni con rilievi tali da garantire un costante deflusso idrico (le bauxiti sono permeabili e quindi poco soggette ad erosione e trasporto a differenza delle argille).

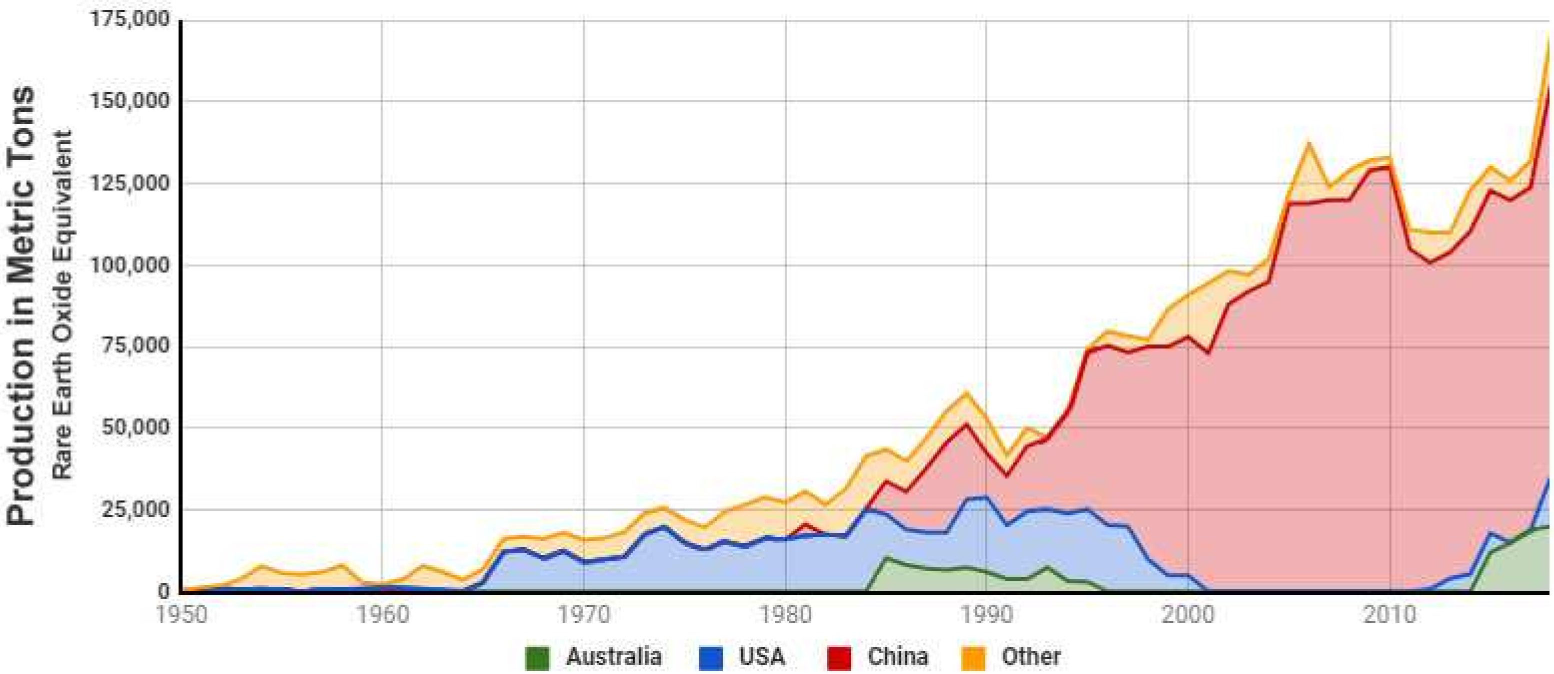
Si sviluppano quasi sempre sopra la superficie freatica, in zone areate e ad elevata esposizione passando attraverso differenziazione mineralogica progressiva ad argille caolinitiche verso il basso.

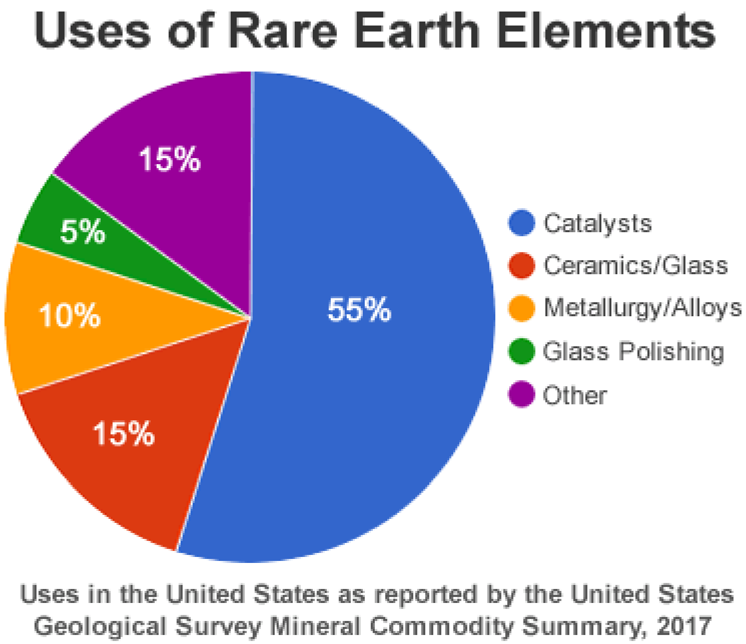
Si trovano quindi su pendii soggetti a buon deflusso.

I depositi residuali accumulati nelle depressioni sono in genere caolinitici.


Rare Earth Elements
by Geology.com
Lanthanides
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Actinides
Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr


Bauxite
Carbonate
Increasing
REE with depth


Production in Metric Tons
Rare Earth Oxide Equivalent
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
1950
1960
1970
1980
1990
2000
2010
Australia
USA
China
Other



Uses of rare earth elements: This chart shows the use of rare earth elements in the United States during 2017. Many vehicles use rare earth catalysts in their exhaust systems for air pollution control. A large number of alloys are made more durable by the addition of rare earth metals. **Glass**, **granite**, **marble**, and **gemstones** are often polished with **cerium oxide** powder. Many motors and generators contain magnets made with rare earth elements. Phosphors used in digital displays, monitors, and televisions are created with rare earth oxides. Most computer, cell phone, and electric vehicle batteries are made with rare earth metals.

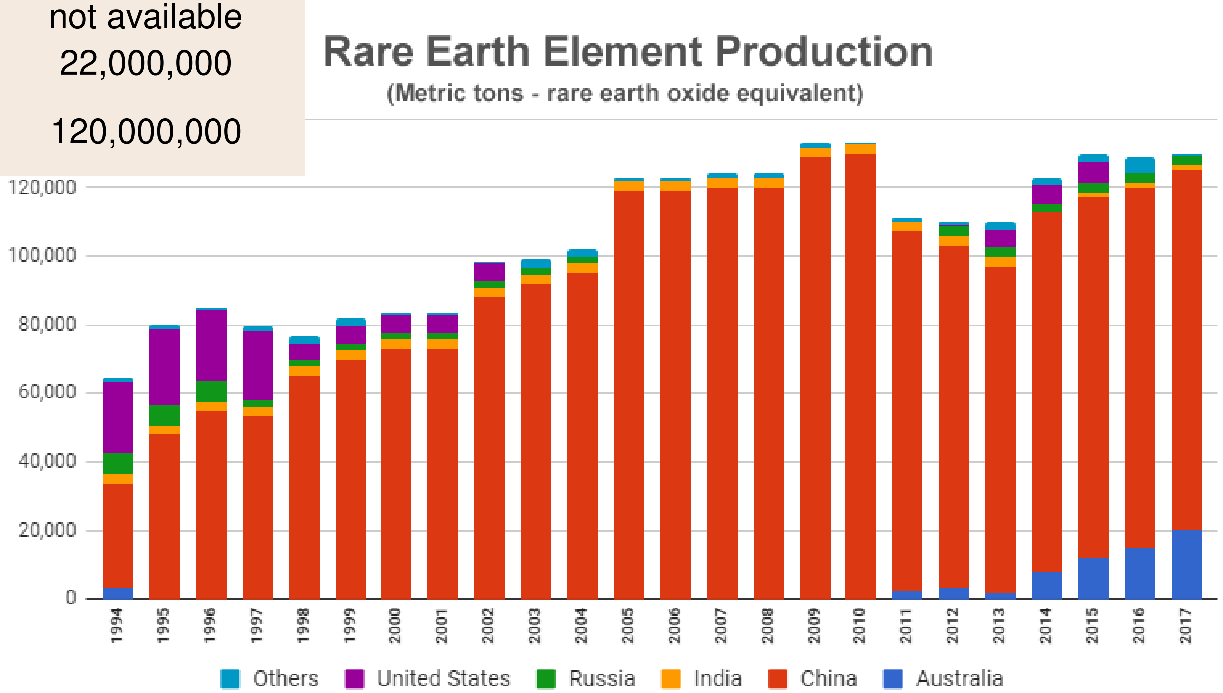
The rare earths for which there is likely to be the greatest demand growth and potential shortage, and which are of the greatest importance for a technologically advanced, clean energy economy, are the so called “Critical Rare Earth Oxides” (“CREOs”) - Neodymium, Europium, Terbium, Dysprosium and Yttrium

Hybrid and electric cars can contain 20–25 pounds[1] of rare earths

(Twice the amount found in standard gasoline cars)

Defense Uses of Rare Earth Elements	
Lanthanum	night-vision goggles
Neodymium	laser range-finders, guidance systems, communications
Europium	fluorescents and phosphors in lamps and monitors
Erbium	amplifiers in fiber-optic data transmission
Samarium	permanent magnets that are stable at high temperatures
Samarium	precision-guided weapons
Samarium	"white noise" production in stealth technology

World Mine Production and Reserves (2017 Estimates)		
Country	**Production (Metric Tons)**	**Reserves (Metric Tons)**
United States	--	1,400,000
Australia	20,000	3,400,000
Brazil	2,000	22,000,000
Canada	--	830,000
China	105,000	44,000,000
Greenland	--	1,500,000
India	1,500	6,900,000
Malawi	--	140,000
Malaysia	300	30,000
Russia	3,000	18,000,000
South Africa	--	860,000
Thailand	1,600	not available
Vietnam	100	22,000,000
World total (rounded)	130,000	120,000,000



minerals

Article

Rare Earth Element Phases in Bauxite Residue

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Abstract: The purpose of present work was to provide mineralogical insight into the rare earth element (REE) phases in bauxite residue to improve REE recovering technologies. Experimental work was performed by electron probe microanalysis with energy dispersive as well as wavelength dispersive spectroscopy and transmission electron microscopy. REEs are found as discrete mineral particles in bauxite residue. Their sizes range from <1 μm to about 40 μm. In bauxite residue, the most abundant REE bearing phases are light REE (LREE) ferrotitanates that form a solid solution between the phases with major compositions (REE,Ca,Na)(Ti,Fe)O_3 and (Ca,Na)(Ti,Fe)O_3. These are secondary phases formed during the Bayer process by an in-situ transformation of the precursor bauxite LREE phases. Compared to natural systems, the indicated solid solution resembles loparite-perovskite series. LREE particles often have a calcium ferrotitanate shell surrounding them that probably hinders their solubility. Minor amount of LREE carbonate and phosphate minerals as well as manganese-associated LREE phases are also present in bauxite residue. Heavy REEs occur in the same form as in bauxites, namely as yttrium phosphates. These results show that the Bayer process has an impact on the initial REE mineralogy contained in bauxite. Bauxite residue as well as selected bauxites are potentially good sources of REEs.

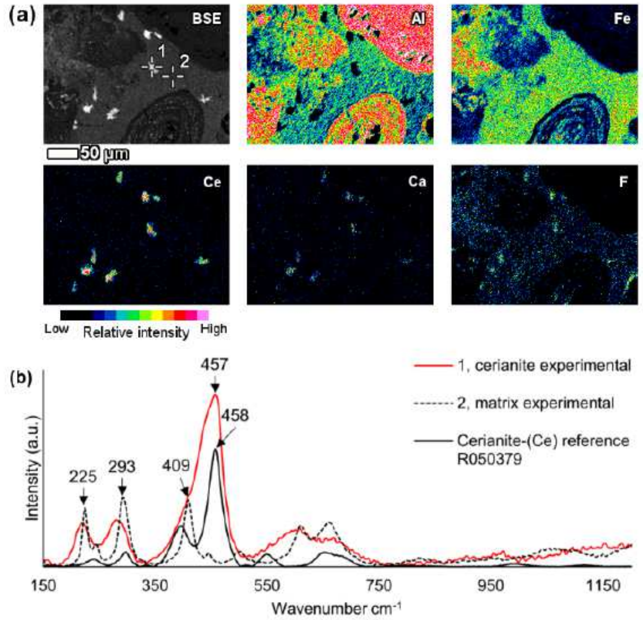

Figure 1. Cerianite rich area in in Parnassos-Ghiona bauxite shown on (**a**) backscattered electron (BSE) image with respective EDS elemental maps, and (**b**) Raman spectra of cerianite and its surrounding matrix compared to reference Raman spectrum obtained from RRUFF database [61], with permission from RRUFF™. Raman spectrum collected with a 532-nm wavelength laser.

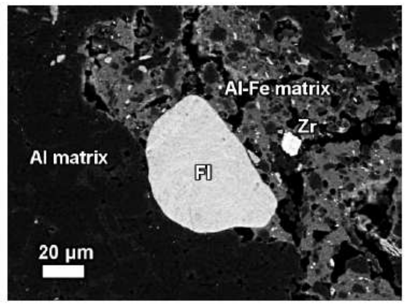

Figure 3. Florencite group LREE phase (Fl) and a zircon grain (Zr) in Ghanaian lateritic bauxite matrix.

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Critical metals distribution in Tethyan karst bauxite: The cretaceous Italian ores

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ABSTRACT

Bauxite is a residual rock, consisting mainly of a mixture of aluminium hydroxides, whose industrial significance is primarily due to its profitably exploitable alumina contents. In the last decades, bauxite, mainly karst bauxite, has been also considered as possible resource of a great number of economically interesting elements including some critical metals such as rare earth elements, Sc, Co, Ni, and Nb. In this study, we present results of univariate and multivariate (R-mode factor analysis) statistics performed on a large data set including chemical composition of the principal Cretaceous karst bauxites from central and southern Italy with the twofold aim to evaluate the inter-elemental relationship among major oxides and critical metals, and describe factors affecting their distribution. Univariate statistics reveal that some critical metals Co, Ni, and LREE, have a significant number of outliers. The Co-Ni relationship associated to the outliers dataset suggests that Co is likely hosted in Ni-rich phases whereas Ce accumulation in authigenic minerals, carbonate-fluoride and phosphate, is at the origin of LREE outliers. Multivariate R-mode statistics, applied to the outliers-devoid database, instead demonstrate that in absence of specific mineralization events, the distribution of most critical metals is controlled by Al-, Fe-, and Ti-oxi-hydroxides and, to a lesser extent, by detrital phases. Among the critical metals, Cr and Y are the exceptions. Their geochemical behaviour seems to be influenced primarily by their own chemical features that are responsible for the mobility of Cr during bauxitization and for the decoupling of Y from the REEs.

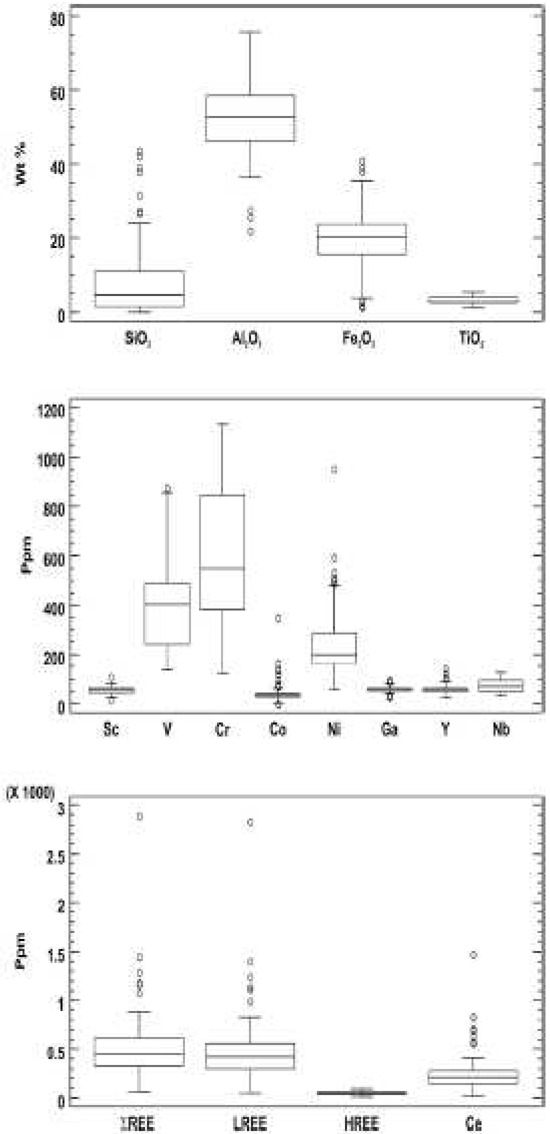


Fig. 3. Box and whisker plots for selected major and trace elements of all analyzed samples. The horizontal bar in the box refers to the median value; the ends of the whiskers are the maximum and minimum values of variables; the top and bottom of the boxes are the values of first and third quartiles; circles represent the outlier values of the dataset.

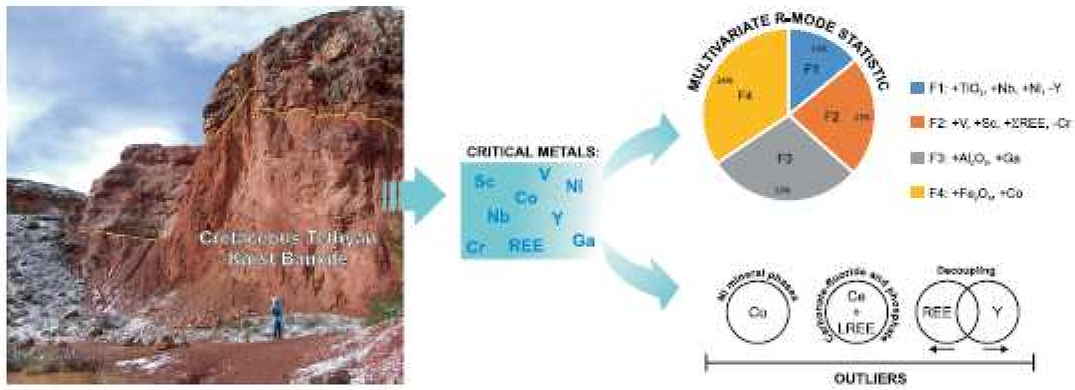


Fig. 4. Schematic representation of results of multivariate R-mode factor analysis and significance of outliers of Tethyan karst bauxites from Italy.

In the karst bauxites of southern Italy and Sardinia Al-minerals mostly form at the expense of kaolinite after silica leaching under tropical climate promoting also TiO_2 accumulation whereas extreme wet climate favour the formation of iron phases. Re-silification processes, due to Tertiary hydrothermal events, can occasionally occur, like those affecting the Sardinian bauxite. Re-silification events in the Sardinian bauxite are clearly associated to the silica outliers thus demonstrating the effectiveness of univariate statistics in unroofing specific mineralisation events. Univariate statistics also indicate that some critical metals, especially Co, Ni, and LREE, have a significant number of outliers. The Co-Ni relationship associated to the outliers suggests that Co is likely hosted in Ni-rich phases whereas Ce accumulation in authigenic minerals, carbonate-fluoride and phosphate, is at the origin of LREE outliers (Fig. 4).

Multivariate R-mode statistics applied to the outliers-devoid database shows that most of the associated variance is explained by factors represented by simple element associations having positive loadings such as TiO_2-Nb, REEs-Sc-V, Al_2O_3-Ga, and Fe_2O_3-Co. This suggests that in absence of specific mineralization events, Al-, Fe-, and Ti-oxi-hydroxides plus detrital phases exert the main control on the distribution of most critical metals (Fig. 4). The fate of the critical metal Cr appears to be different from those of other critical trivalent and largely insoluble metals, being affected by a redox chemistry promoting its mobility as Cr^{6+}.

It has been observed that Y, whose behaviour usually mirrors that of the HREE, in the considered bauxites does not follow this behaviour in the outliers-devoid database, and has different outliers from those observed for the HREE. This behaviour may suggest that, during bauxitization, Y may suffer a decoupling from the REEs pool (Fig. 4).

Genesi e geochimica delle bauxiti: un breve riassunto.

La formazione dei depositi bauxitici è quindi governata da più fattori:

-elementi e minerali presenti nella roccia madre

-condizioni climatiche

-associazione degli elementi in minerali stabili ed instabili durante i processi di "weathering"

-intensità del drenaggio idrico (verticale e/o orizzontale)

-variazione del pH delle soluzioni acquose

-precipitazione (o ricristallizzazione) in situ

-trasporto

-risedimentazione e diagenesi.

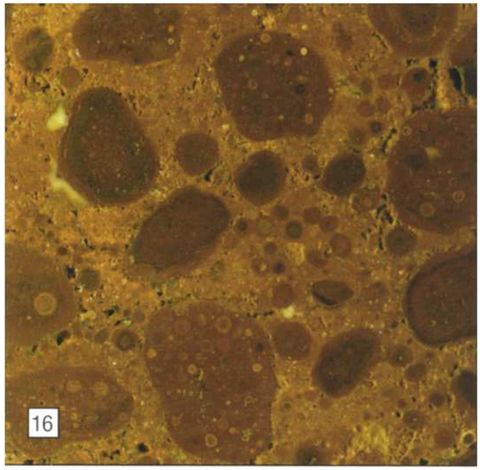
Gli elementi più importanti sono Al, Fe e Si.

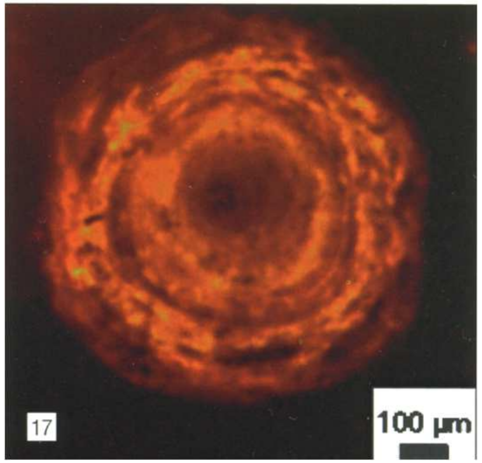
Con la rimozione della silice il deposito tende ad arricchirsi di Al e Fe ed il rapporto Al/Fe dipende strettamente dalla sorgente di rocce madri.

La natura delle rocce madri d'origine dipende strettamente dai prodotti detritici già in corso di alterazione presenti a alti livelli topografici

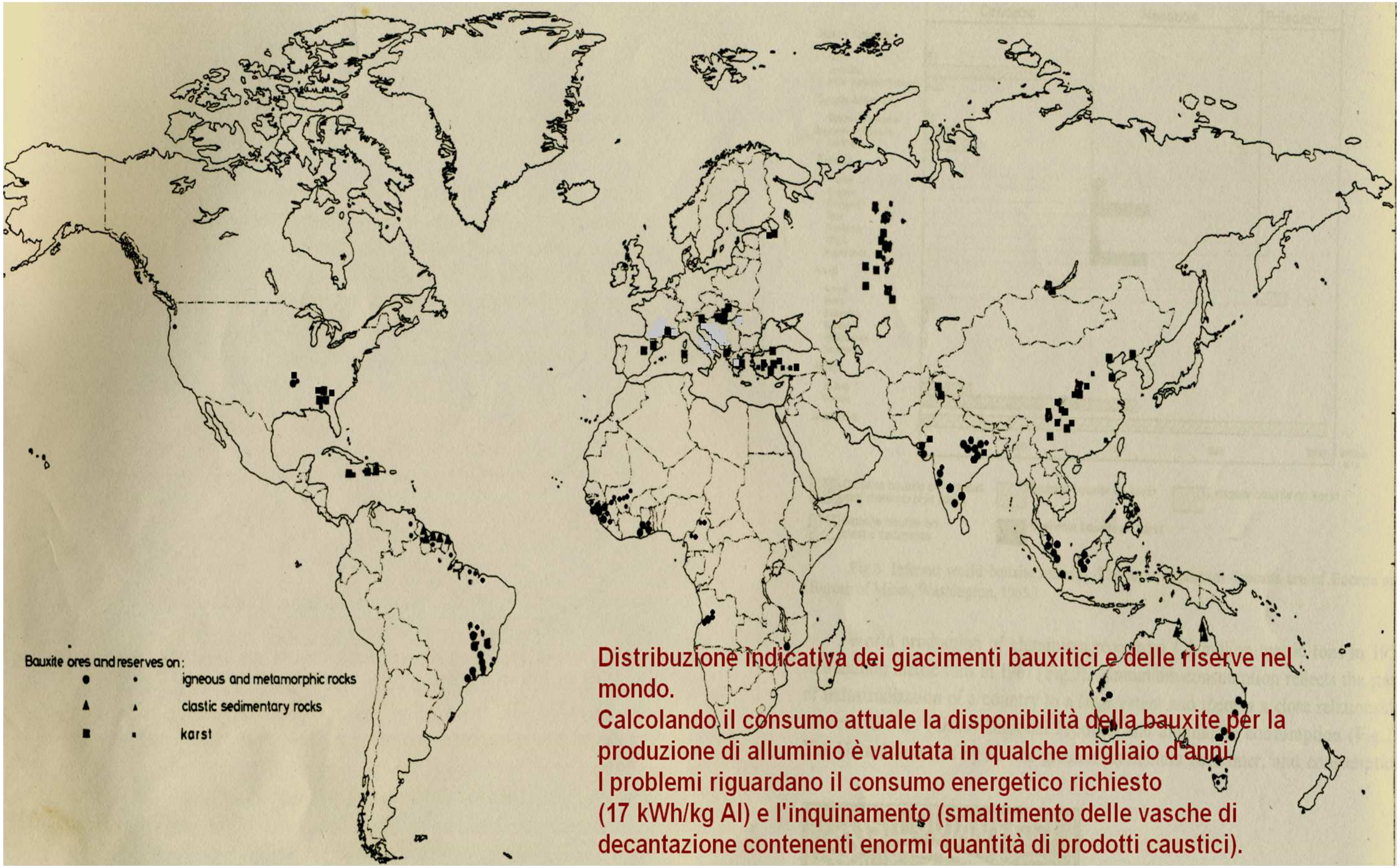
Tutto ciò condiziona sia la mineralizzazione sia la tessitura delle bauxiti.

Naturalmente il fattore fondamentale è la scarsa mobilità di Al.



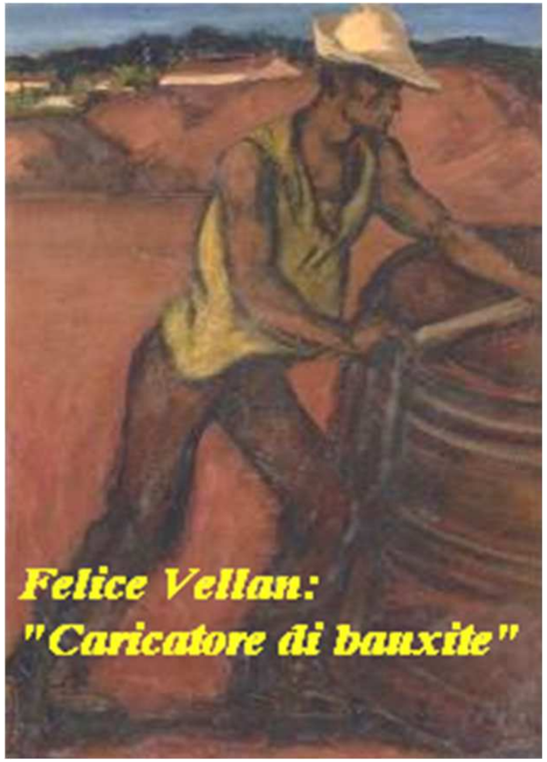


Diffusione dei giacimenti, estrazione, produzione di alluminio, previsioni sul consumo: una mappa geografica delle bauxiti.



Distribuzione indicativa dei giacimenti bauxitici e delle riserve nel mondo.
Calcolando il consumo attuale la disponibilità della bauxite per la produzione di alluminio è valutata in qualche migliaio d'anni.
I problemi riguardano il consumo energetico richiesto (17 kWh/kg Al) e l'inquinamento (smaltimento delle vasche di decantazione contenenti enormi quantità di prodotti caustici).

Major Export Countries



Nation	2006	2007	2008	2009	2010	2011
Indonesia	7.27	11.66	16.79	14.72	27.41	40.64
Australia	5.51	7.16	8.66	6.37	7.95	10.29
Jamaica	14.72	14.51	14.72	8.1	8.49	10.06
Brazil	5.31	5.78	6.22	3.04	6.79	6.89
Greece	0.91	1.09	0.79	0.41	0.43	0.52
India	3.49	6.39	3.52	0.27	0.25	0.43
Total	**37.22**	**46.59**	**50.7**	**32.92**	**51.35**	**68.83**

World bauxite export trade is growing. In 2011, the total export volume f the countries listed was 68.83 million tonnes, up by 85% over that of 2006.

Indonesia is the standout country.Its exports have leapt from only 7 million tonnes in 2006 to over 40 million tonnes in 2011. This situation could change rapidly however as the Indonesian government intends to introduce a ban on raw materials exports commencing 2014. The exports from other counties are relatively stable.

Major Import Countries

No.	Nation	2006	2007	2008	2009	2010	2011
1	China	9.26	23.28	25.93	19.8	30.36	45.24
2	USA	11.6	11.79	12.47	7.92	7.32	9.47
3	Ukraine	3.12	3.62	3.92	3.9	4.46	4.92
4	Ireland	3.37	4.13	3.01	2.79	4.11	4.22
5	Canada	3.29	3.34	3.56	2.3	3.37	3.2
6	Spain	3.01	3.55	3.62	3.51	3.33	3.08
7	Germany	2.14	3.14	3.01	2.12	2	2.44
8	France	1.67	2	1.79	1.02	0.96	1.44
9	Japan	1.69	1.99	2.07	1.18	1.16	0.99
10	Azerbaijan	1.23	0.75	0.89	-	-	0.06
11	Italy	2.62	2.36	2.42	0.04	0.06	0.05
	Total	**42.99**	**59.96**	**62.69**	**44.58**	**57.15**	**75.1**

China is the largest aluminium consuming and bauxite importing country in the world.
In 2011, China's aluminium consumption reached 17.629 million tonnes, accounting for over 40% of world's total; followed by the USA (9.6% of world's total).
Commensurate with its increased consumption of aluminium, China's bauxite imports have increased 5 fold in the period 2006-2011. In 2011 China accounted for 60% of all bauxite imports.

Bauxite Mining

Typical Bauxite Mining Process

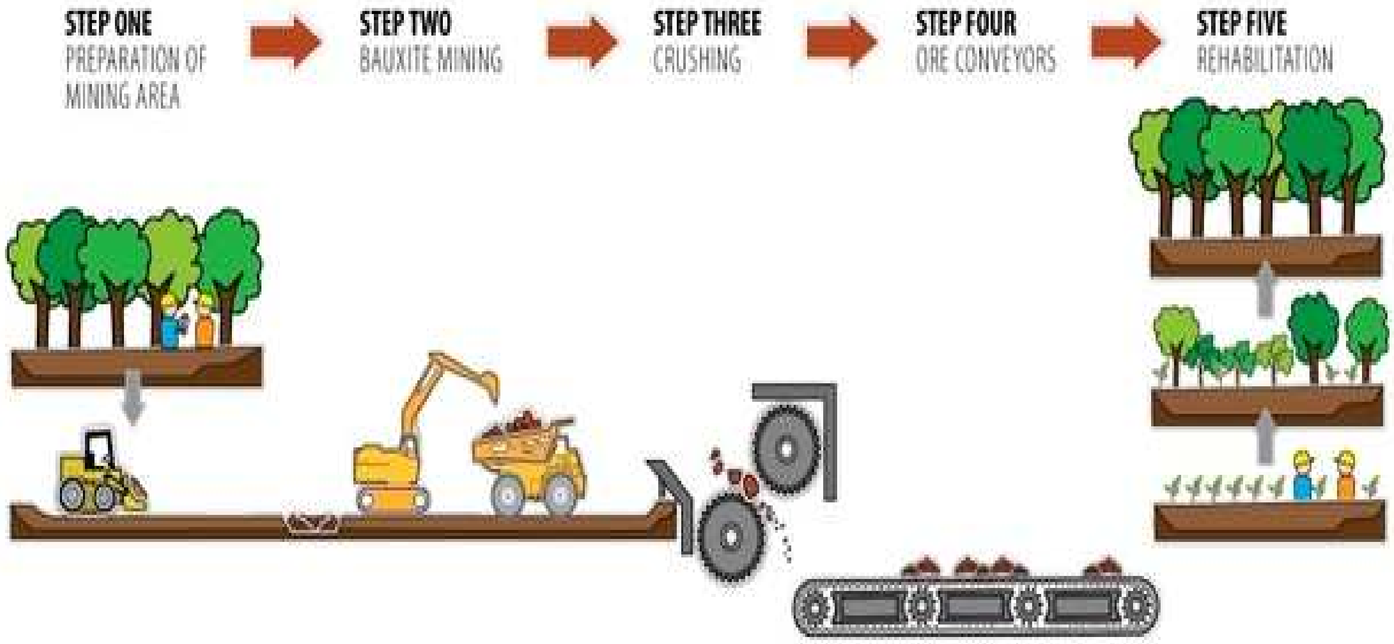
Vegetation is cleared and top soil is removed and set aside for rehabilitation

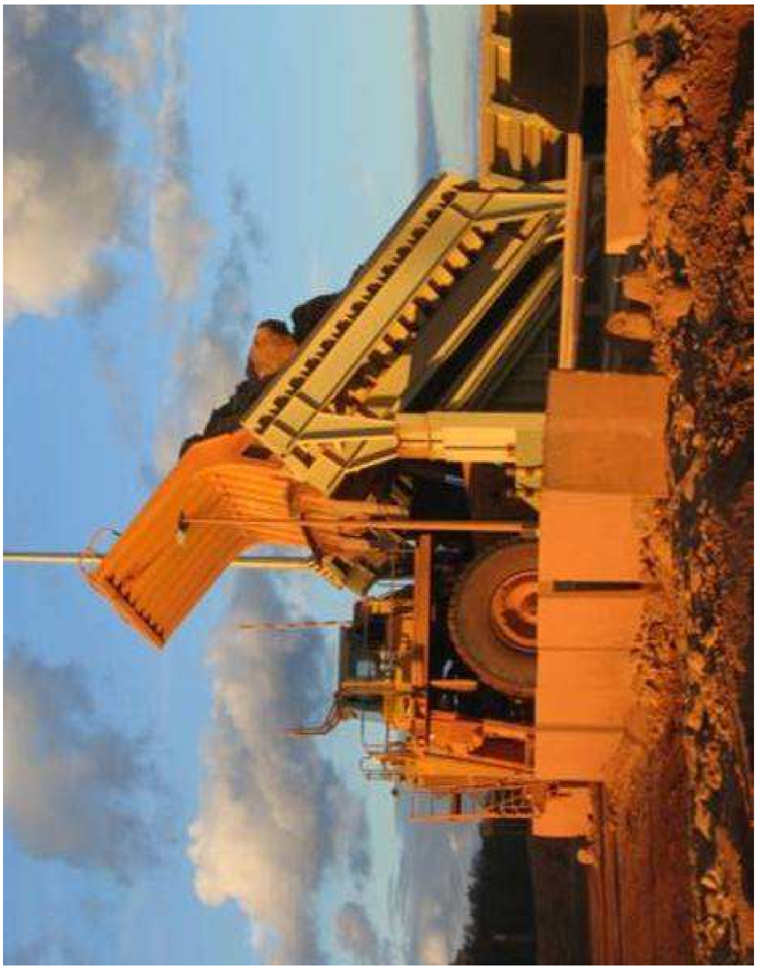
Scrapers and excavators are used to remove the remaining overburden and expose the cap rock.

Depending on the depth of the cap rock, it can be broken by blasting, or simply removed with scrapers and excavators

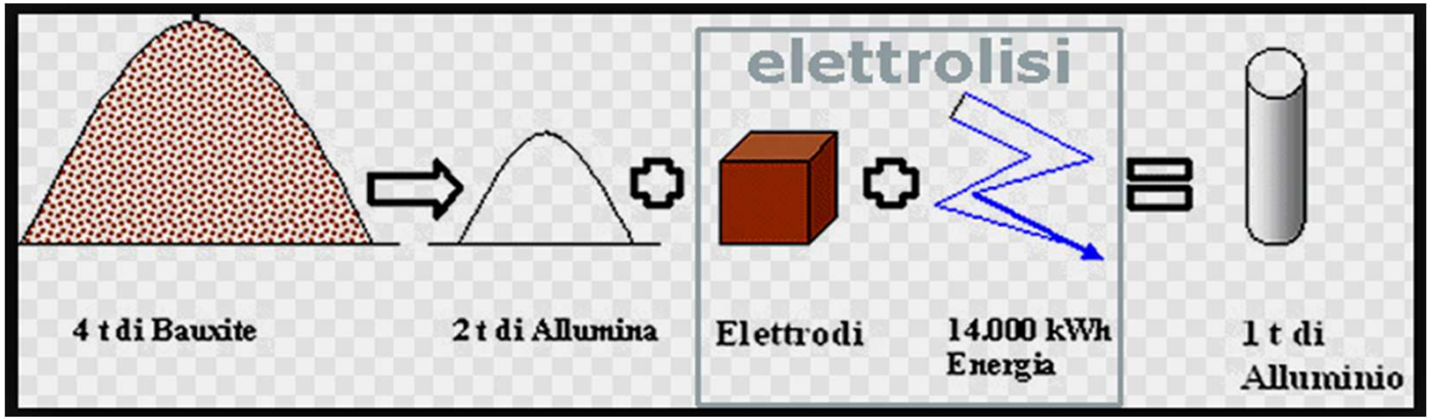
The bauxite is then mined using excavators or loaders. Off road haul trucks transported the bauxite to the crusher. Several pits are usually mined simultaneously in order to supply the refinery with a consistent grade of ore.

The mined out area is backfilled with the removed over burden, the set aside top soil is redeposited, then re-vegetated with plants indigenous to the area.

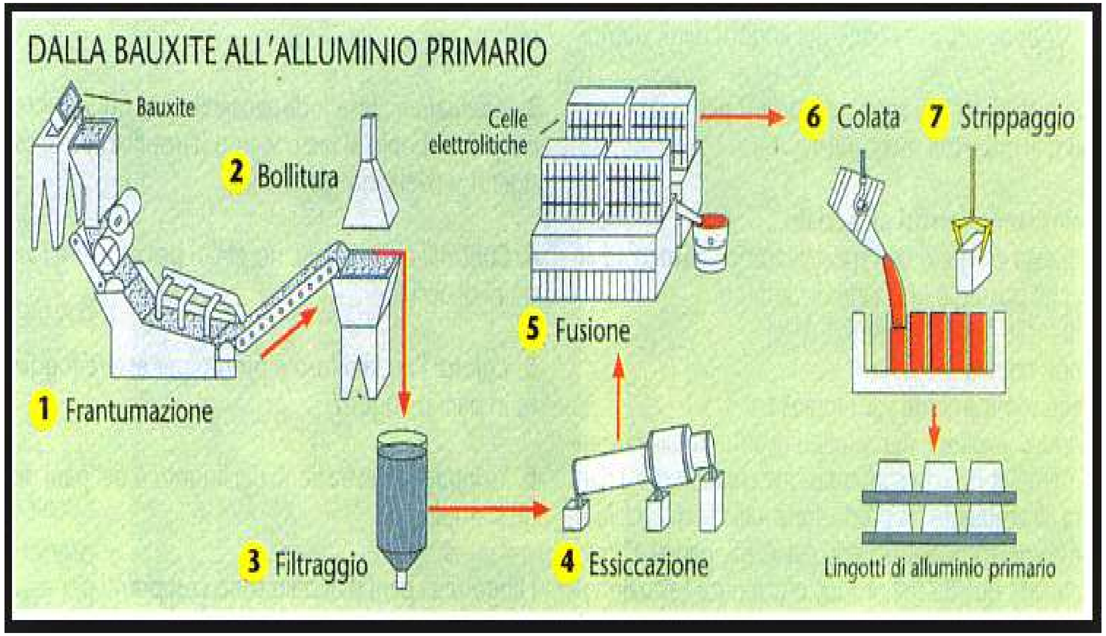


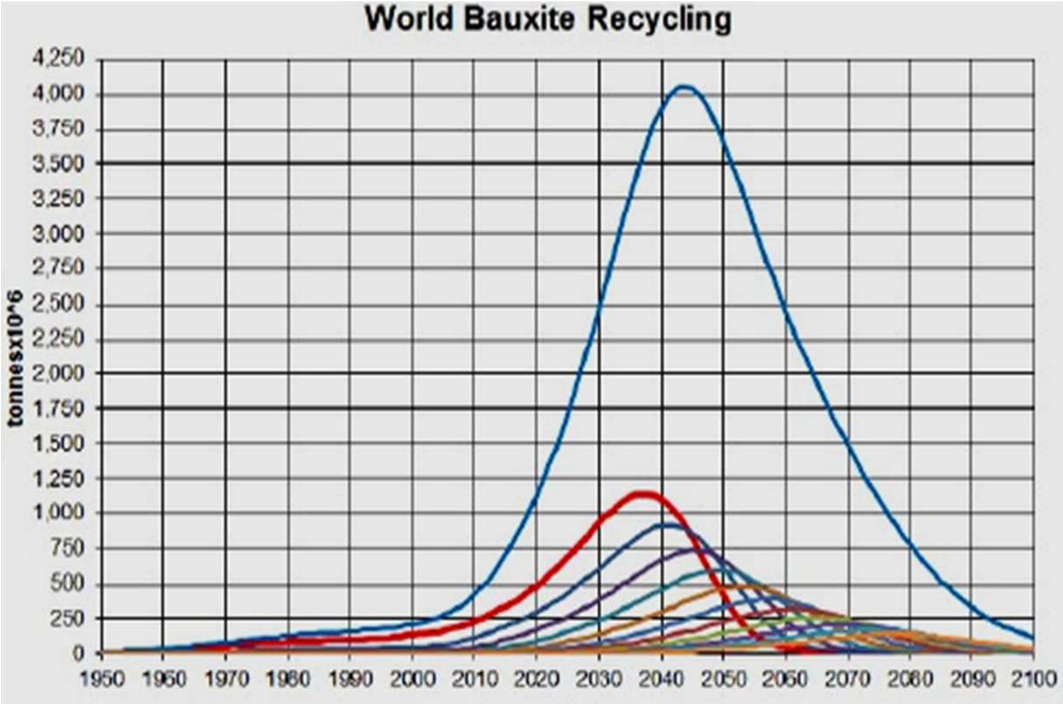


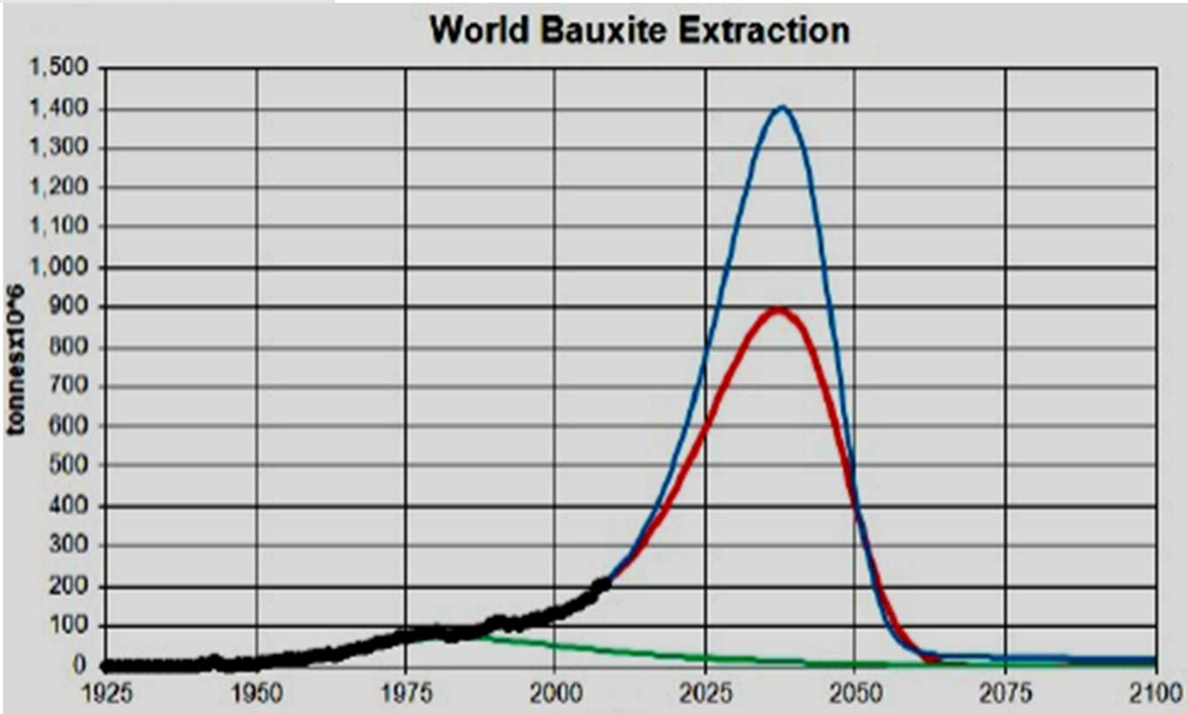
La bauxite è l'unico minerale dal quale può essere estratto l'alluminio. I processi di trasformazione usati sono diversi ma sostanzialmente consistono tutti nella produzione finale del metallo puro attraverso l'elettrolisi di allumina Al_2O_3. In questo procedimento finale per ogni chilogrammo di alluminio vengono consumati 14 KW/h ai quali si aggiungono 3 KW/h per la formazione di allumina quindi 17 KW/h.



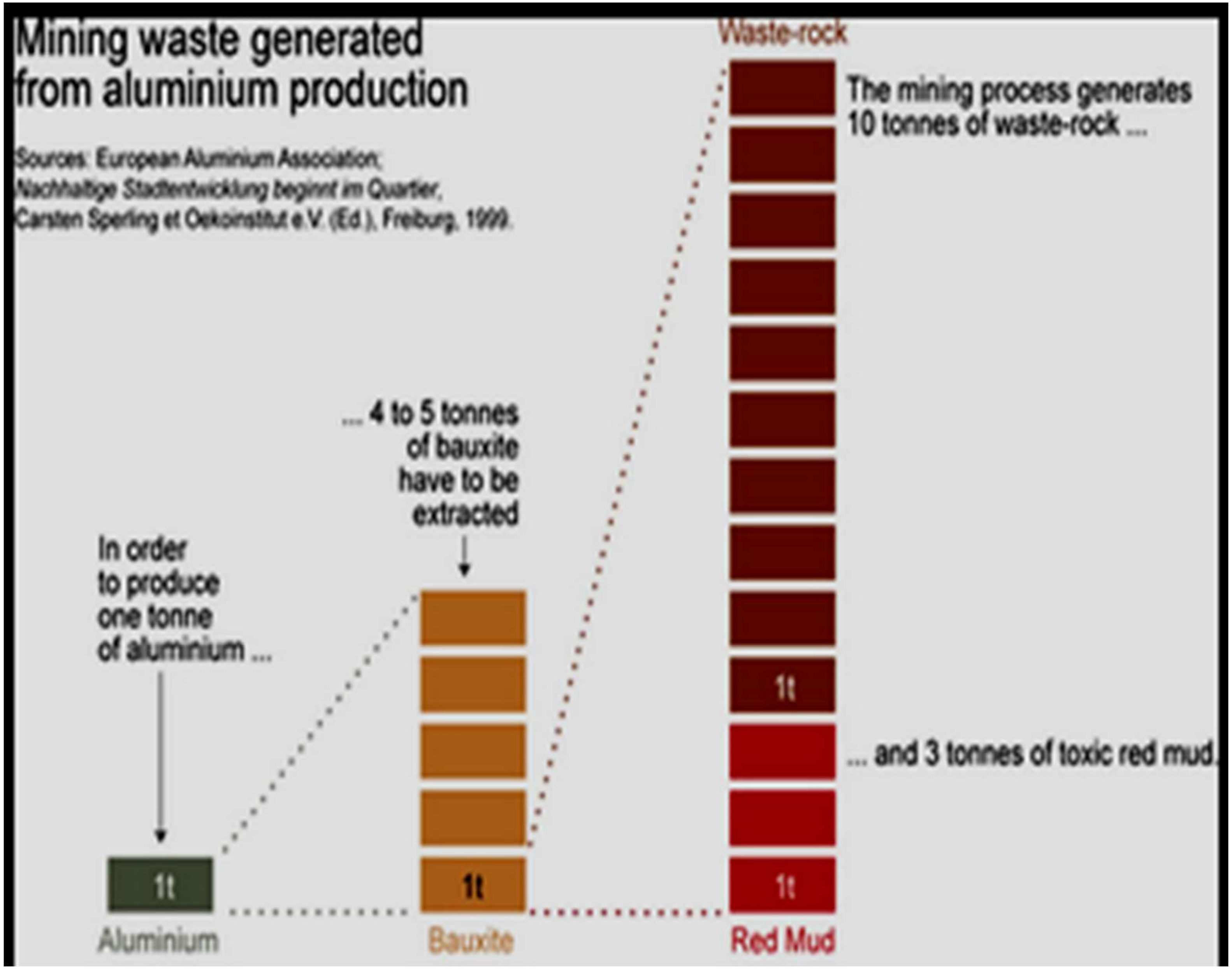
La produzione di Al non comporta solamente alti consumi energetici (17 KW/h per Kg di Al) ma anche elevati costi per la gestione degli impianti e per lo smaltimento dei fanghi rossi derivati dalle prime fasi di lavorazione.




World Bauxite Recycling
tonnesx10^6
4,250
4,000
3,750
3,500
3,250
3,000
2,750
2,500
2,250
2,000
1,750
1,500
1,250
1,000
750
500
250
0
1950 1960 1970 1980 1990 2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100


World Bauxite Extraction
tonnesx10^6
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
1925 1950 1975 2000 2025 2050 2075 2100

L’impatto delle estrazioni sulla produzione di scarti.



Devastazione e riparazione del territorio

Da decenni sono iniziati in alcuni paesi i processi di riparazione dell'ambiente gravemente danneggiato dalle cave di bauxite: consistono soprattutto nella fitoriparazione e nel lento recupero dei terreni riconsegnati all'agricoltura. In alcuni centri di ricerca si sta sperimentando l'uso di bauxite trattata termicamente per l'abbattimento di cromo, arsenico, fosfati e fluoruri dalle acque.