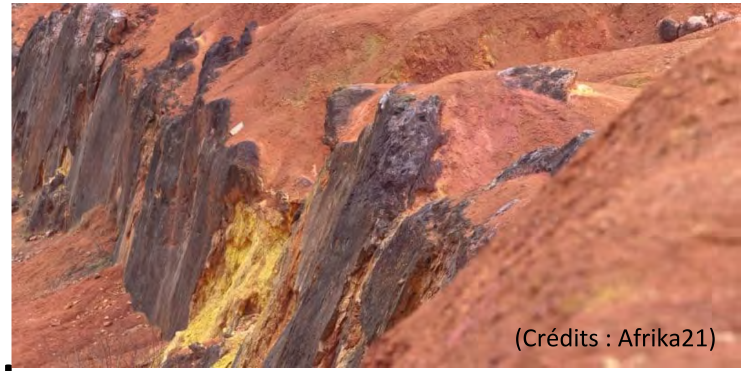

(Marchand et al, 2020)

Bauxite Overview :
Genesis, Occurrence,
Aluminium supplies and Life cycle


(Crédits : Reuters)

Jean – Paul AMBROSI

CNRS – CEREGE – EQ. Environnement Durable


(Crédits : Afrika21)

Journées Scientifiques :
"Bauxite Résidues"
Aix-en-Provence, du 08 au 09 juin 2021

Bauxite or rather bauxites are materials formed by meteoric weathering in a tropical climate. These are thus laterites in the broad sense for which the processes of relative and / or absolute accumulation of aluminum are predominant (ferrallitization, allitization).

These materials, due to their high Al content but conversely low in Fe and especially Si, constitute the main ore in the manufacturing and processing industry of alumina and aluminum.

We distinguish (Bardossy, 1981) three types of bauxite according to their mode of formation, the origin of the parent-material and the typology of their deposit.

- karst bauxites most often of allochthonous origin by ferrallitization of parental material brought by erosion and transport in the karstified networks of carbonate formations which constitute their deposit (mined and exploited in galleries).
- lateritic bauxites called bauxitic laterites most often indigenous formation by in situ chemical weathering of parental material (aluminosilicates rocks) giving rise to thick vertical profiles (mined in an open pit).
- *Tikhvin-type bauxites — detrital deposits of eroded lateritic bauxites. Bogatyrev et al. (2009) classified this type as "sedimentary bauxites".*

Mineralogically, aluminum is expressed:

- in karst bauxites mainly in the form of oxihydroxides AlO(OH) boehmite and diaspore, and hydroxide $Al(OH)_3$ gibbsite
- in lateritic bauxites, boehmite and gibbsite are the main carrier phases
- corundum Al_2O_3 possibly present in both types (relict from parent-rock)

from wikipédia

composé	bauxite de karst	bauxite latéritique
	en % du minerai sec	
Al_2O_3	48 à 60	54 à 61
SiO_2	3 à 7	1 à 6
Fe_2O_3	15 à 23	2 à 10
TiO_2	2 à 3	2 à 4
CaO	1 à 3	0 à 4
H_2O (combiné)	10 à 14	20 à 28
Zn, V, C organique	traces	-

Raw materials :

Aluminum, in the oxidized state, is the most common metallic element in the earth's crust, with an Al content of 8% or 15% expressed as alumina, Al_2O_3. It is the third element after oxygen and silicon.

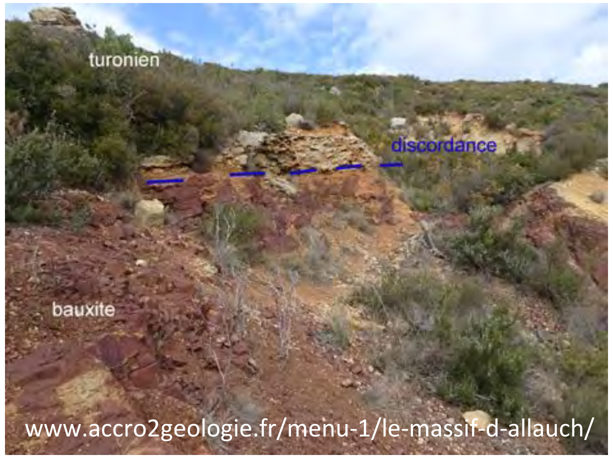
Al is mainly present in the form of aluminosilicates in clays, shales, etc. containing from 18 to 38% of Al_2O_3, but it is more economical to recover the alumina from the bauxites properly speaking (bauxite from karts present mainly in Europe, with low reserves) or bauxitic laterites (present in tropical climates, with large reserves). By generalization, bauxitic laterites are also called bauxites.

The majority of karst bauxites are located in the northern hemisphere, in most cases outside regions currently characterized by tropical to sub-tropical climates. This is because they represent fossil bauxites, formed in past geological periods (e.g., Paleozoic or Mesozoic) when more favorable climatic conditions prevailed.

The karst bauxites rest on a wall still limestone or dolomitic; they are often sealed in their deposit by sedimentary foundations which constitute their roof, which can be of various types, ages and origins. This roof interferes with the exploitation of karst bauxites: it requires either the extraction of bauxite in underground mining, or the clearing of a sometimes significant amount of overburden, during quarrying.

They appear at different stratigraphic levels in different parts of the globe; thus we know such bauxites on Cambrian in Siberia, on Silurian in the Urals, on Devonian in the Urals and in the Salair, on the Carboniferous in the United States, on the Triassic in Hungary, in Greece, in the Montenegro, over Jurassic in India, in France, over Lower Cretaceous in France, over Upper Cretaceous in Yugoslavia.


la-mine-de-Baume-Nord-de-la-Carrire/

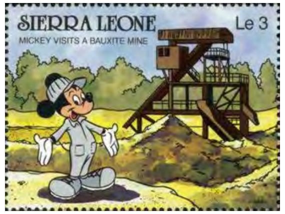


www.accro2geologie.fr/menu-1/le-massif-d-allauch/


Bauxite mining at Bauxite (Saline County); 1912. Photo courtesy of Butler Center for Arkansas Studies, Central Arkansas Library System.


Pisolitic bauxite from Arkansas, Photo by James St. John

Various facies of the Guinean Lateritic Bauxite
Courtesy CPMB, The Republic of Guinea



Surinamese lateritic bauxite

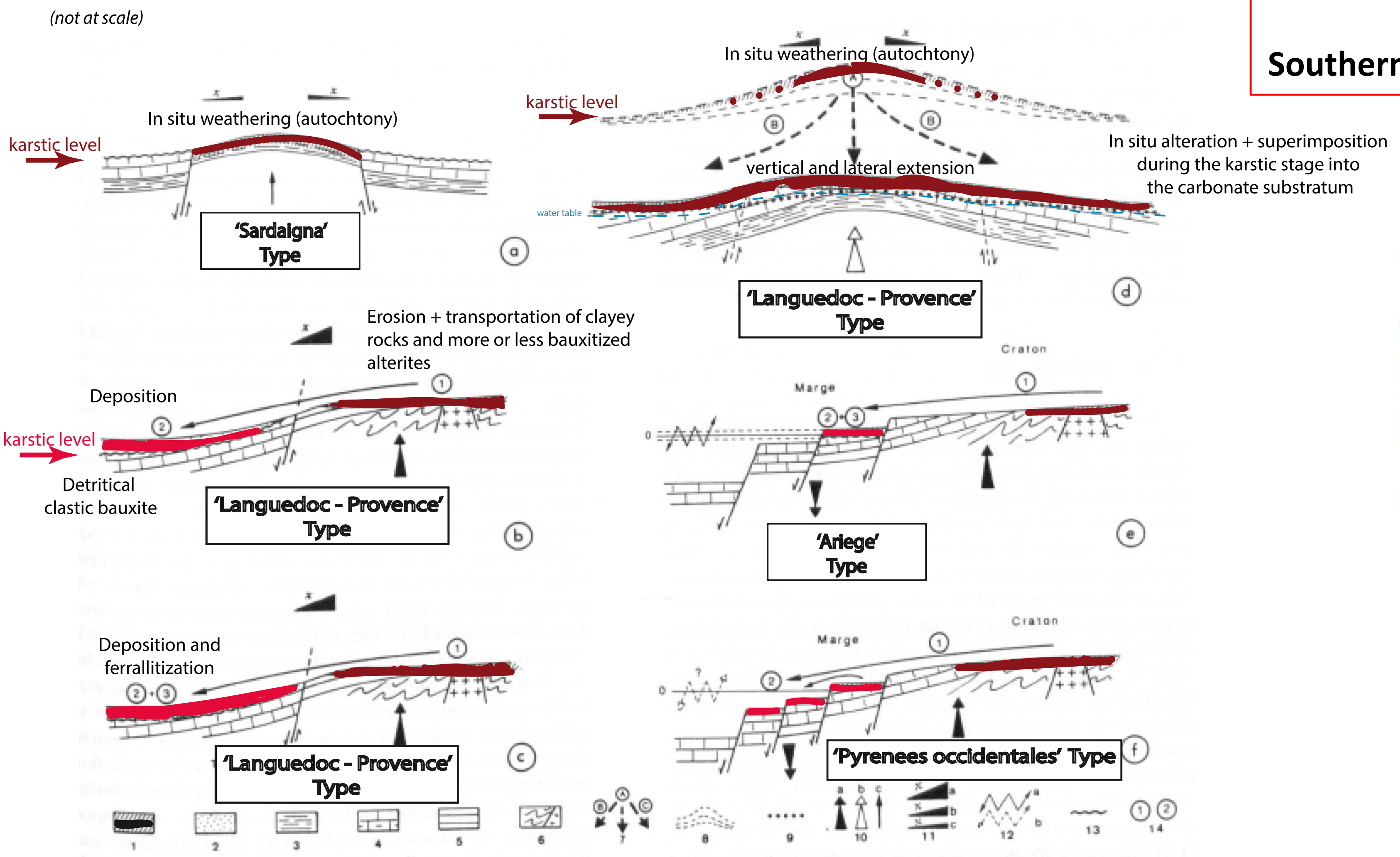
Lateritic bauxites are generally located in regions currently characterized by tropical to sub-tropical climates and, more extensive examples started to form in Late Cretaceous times, experiencing peaks of intense lateritic weathering in the Paleocene-Eocene and the Middle Miocene.

They are a product of continental weathering, of a pedogenetic order, under the influence of the aggressive climates currently known in the intertropical zone. Laterites can cover large areas forming a surficial weathering layer of approximately constant thickness (plurimetric)

Almost all rocks contain minerals containing Al. Lateritic bauxites can form from felsic igneous rocks, clayey limestones, clayey clastic rocks. The rock must be permeable (fracture, porosity) to allow the circulation of water. The transition from volcanic or plutonic protolith to porous and friable laterite is gradual, and the parent rock texture is preserved during the first stage of lateritization.

In summary, the structure of aluminosilicate minerals is gradually destroyed and elements like Si, Na, K, Ca are leached, leaving a residue rich in Al and often associated with iron forming various weathering layers.

Karst bauxites
Southern France as an example

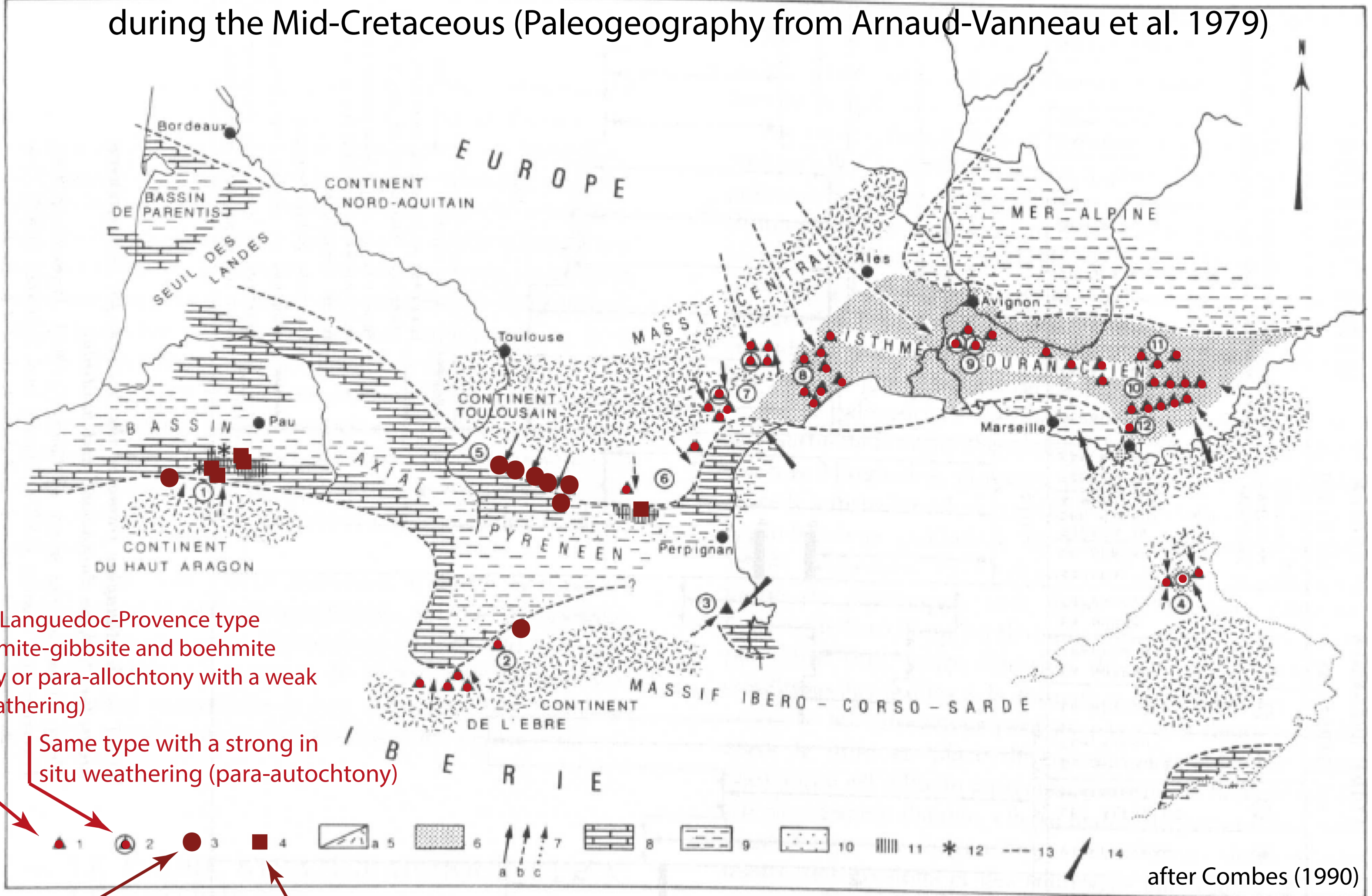


The main mode of karst bauxites formation on carbonate basement

After Combes (1990) Geodinamica Acta, 4:2, 91-109

Distribution of the main type of deposits on the craton and the european and iberian margin during the Mid-Cretaceous (Paleogeography from Arnaud-Vanneau et al. 1979)

Outcrop of bauxites (in red) in the Upper Jurassic (shades of gray) karstified by preferential dissolution along a network of orthogonal joints (N060 and N150). Exploitation of Lake Olivet, Villeveyrac.
http://www.gm.univ-montp2.fr/spip.php?article3332



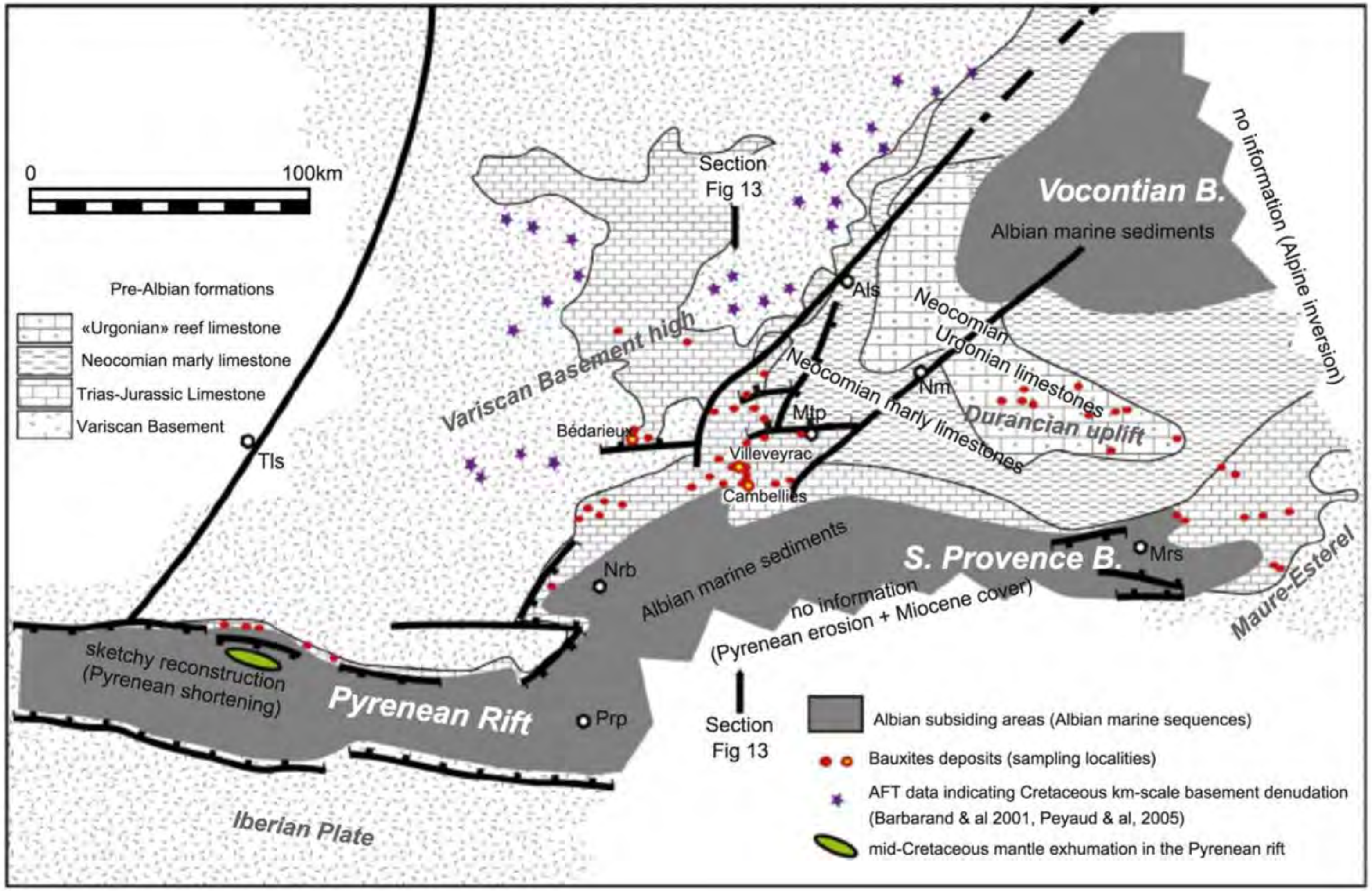
Bauxite of Languedoc-Provence type with boehmite-gibbsite and boehmite (allochtony or para-allochtony with a weak in situ weathering)

Same type with a strong in situ weathering (para-autochtony)

Bauxite de type Ariege, à boehmite-diaspore (para-autochtony)

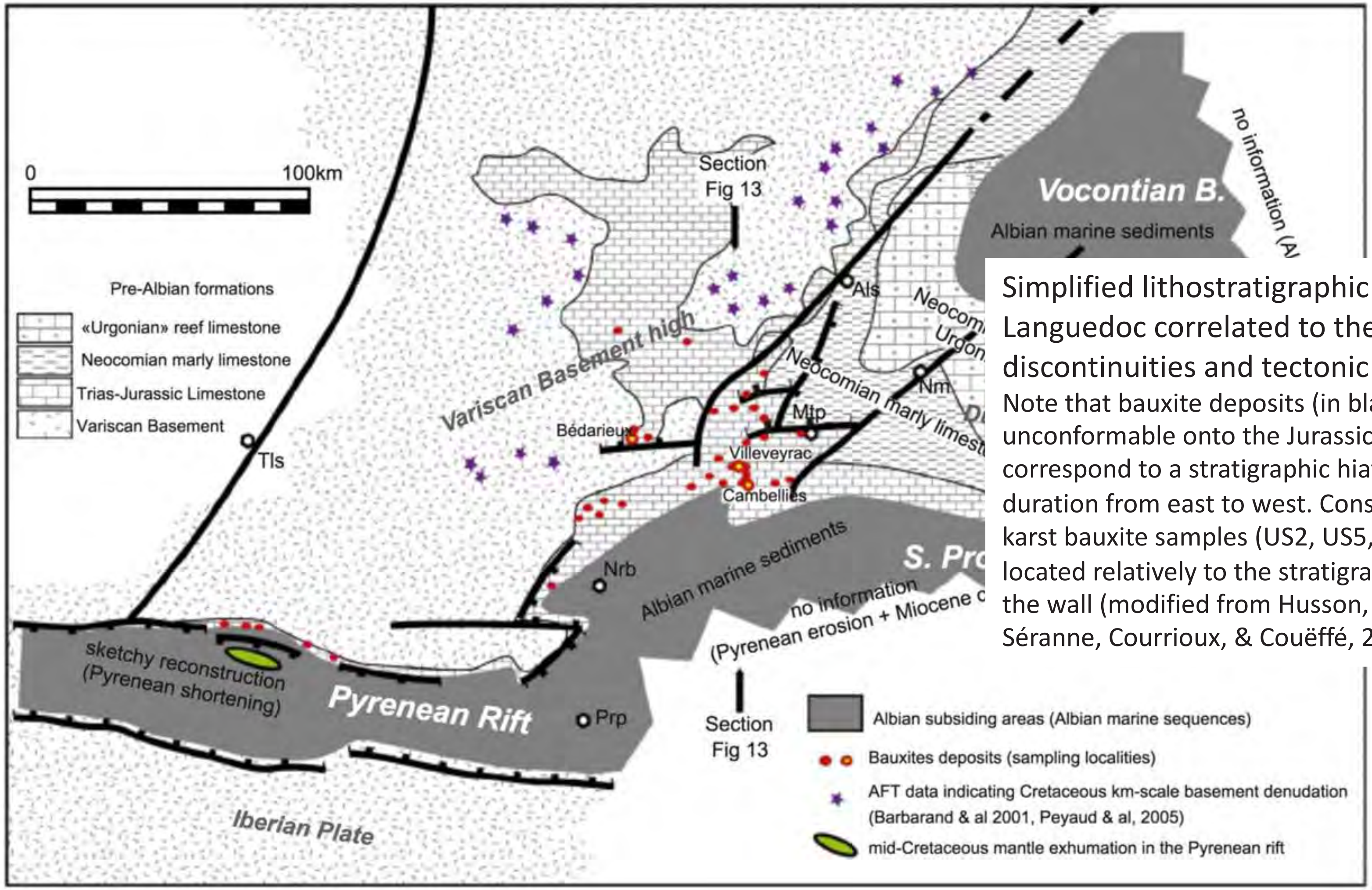
Bauxite of Pyrenees occidentales type with diaspore-chlorite (mainly allochtony)

after Combes (1990)



Interpreted structural and paleogeographic map during mid-Cretaceous time in Southern France

Marchand, E., Séranne, M., Bruguier, O., and Vinches, M., 2020, LA-ICP-MS dating of detrital zircon grains from the Cretaceous allochthonous bauxites of Languedoc (south of France) : Provenance and geodynamic consequences. Basin Research, doi : 10.1111/bre.12465

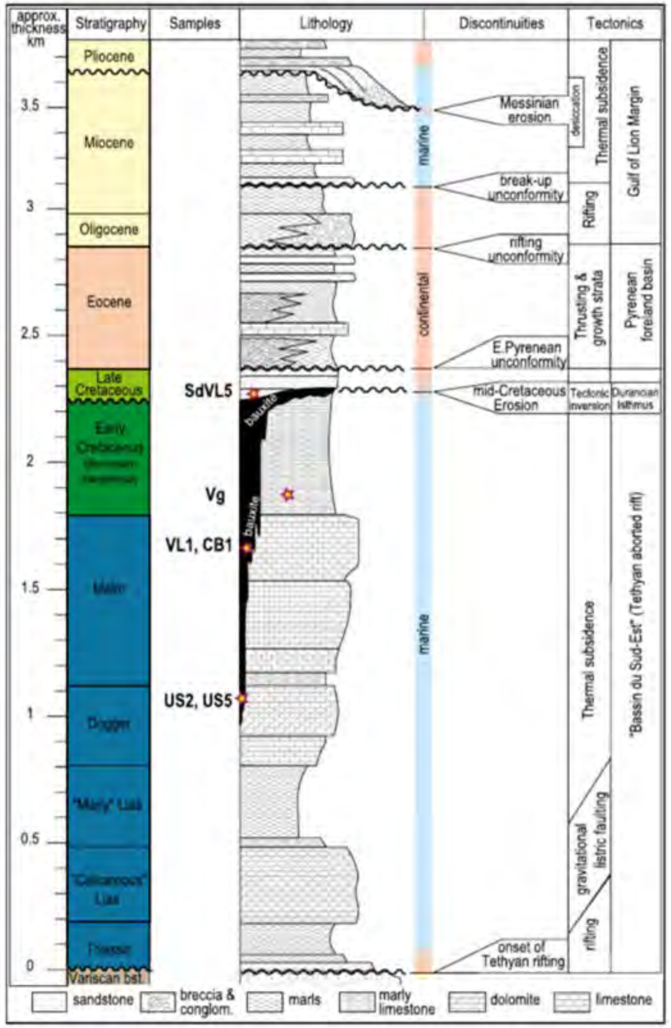


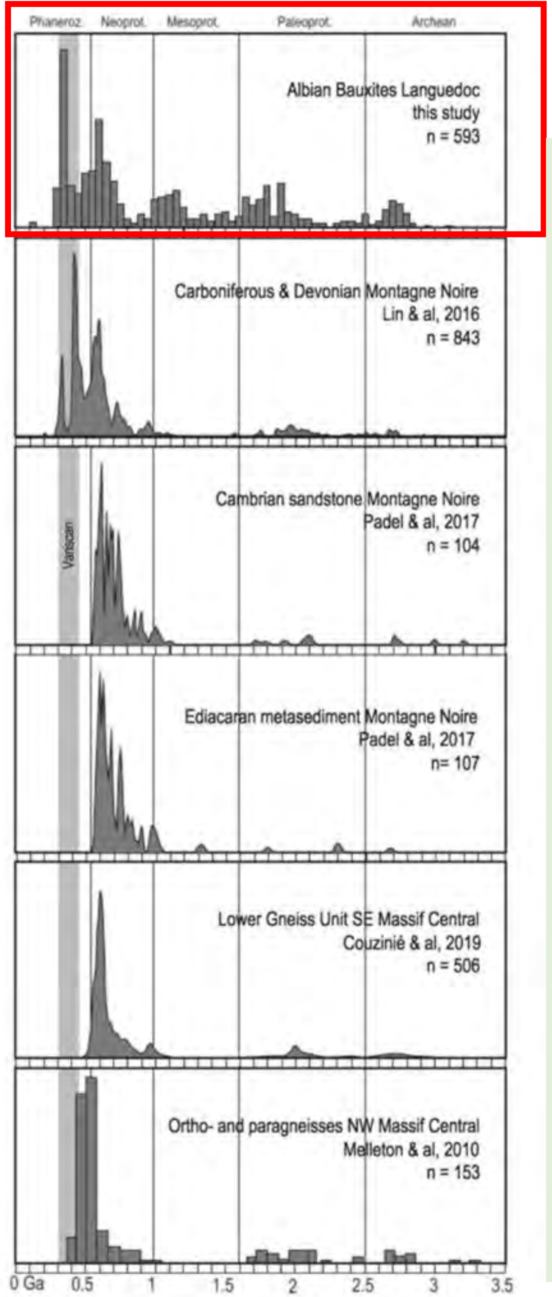
Interpreted structural and paleogeographic map during mid-Cretaceous time in Southern France

Marchand, E., Séranne, M., Bruguier, O., and Vinches, M., 2020, LA-ICP-MS dating of detrital zircon grains from the Cretaceous allochthonous bauxites of Languedoc (south of France) : Provenance and geodynamic consequences. Basin Research, doi : 10.1111/bre.12465

Simplified lithostratigraphic column of Languedoc correlated to the main discontinuities and tectonic events.

Note that bauxite deposits (in black) are highly unconformable onto the Jurassic sequence, and correspond to a stratigraphic hiatus of increasing duration from east to west. Consequently, the karst bauxite samples (US2, US5, VL1, CB1) are located relatively to the stratigraphic position of the wall (modified from Husson, Guillen, Séranne, Courrioux, & Couëffé, 2018)

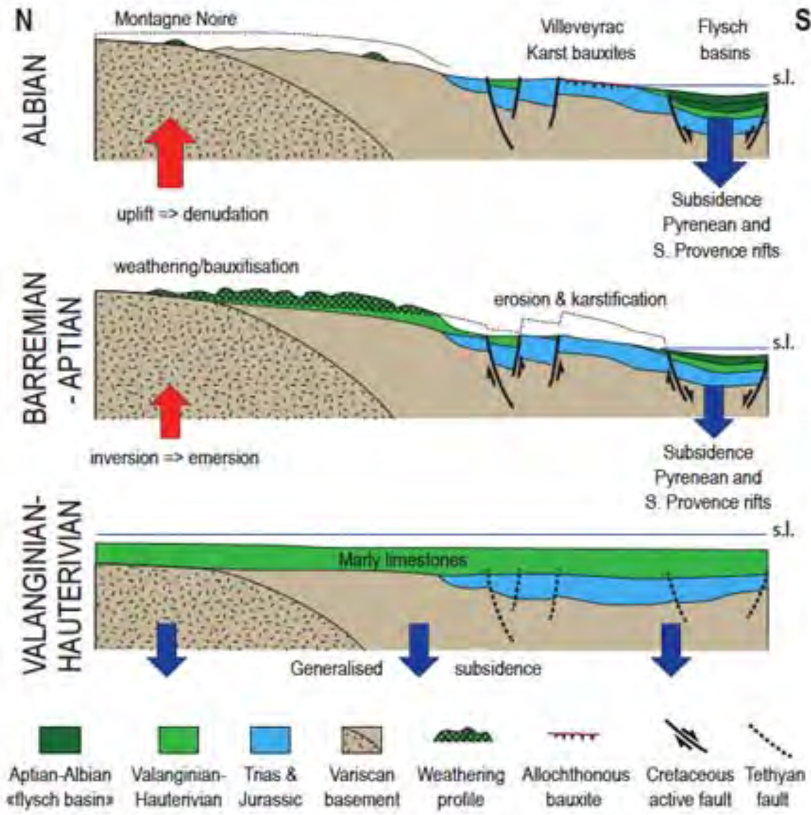


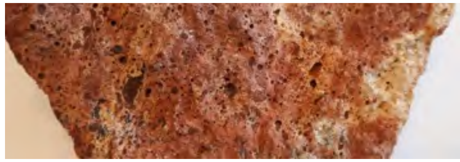


Marchand, E. et al.2020, 10.1111/bre.12465

Abstract

The Cretaceous of southern France is characterised by a long erosional hiatus, out-lined with bauxite deposits, which represent the only remaining sedimentary record of a key period for geodynamic reconstructions. Detrital zircons from allochthonous karst bauxites of Languedoc (Southern France) have been dated using LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry), in order to specify the age of deposition and to constrain the provenance of the weathered material. We analysed 671 single detrital zircons grains from three karst bauxitic basins, stretching from close to the Variscan Montagne Noire to the present-day Mediterranean Sea. Analytical results provide Variscan (300–350 Ma) and Late Proterozoic (550–700 Ma) ages as primary groups. In addition, Middle-, Late Proterozoic and Early Archean (oldest grain at 3.55 Ga) represent significant groups. Mid-Cretaceous zircons (118–113 Ma) provide a pooled age of 115.5±3.8 Ma, which constitutes the maximum age for bauxite deposition. Results also suggest a dual source for the Languedoc bauxite: one generalised sedimentary source of regional extent and a localised source in the Variscan basement structural high, that has been progressively unroofed during Albian. Integration of these new findings with previously published thermochronological data support the presence of an Early Cretaceous marly cover on the Variscan basement, which has been weathered and then, removed during the Albian. The Languedoc bauxite provide a spatial and temporal link between the up-lift of southern French Massif Central to the north, and the Pyrenean rift and its eastward extension to the south. These new results allow to constrain the timing and distribution of uplift/subsidence during the mid-Cretaceous events in relation with the motion of the Iberian plate relative to Eurasia.





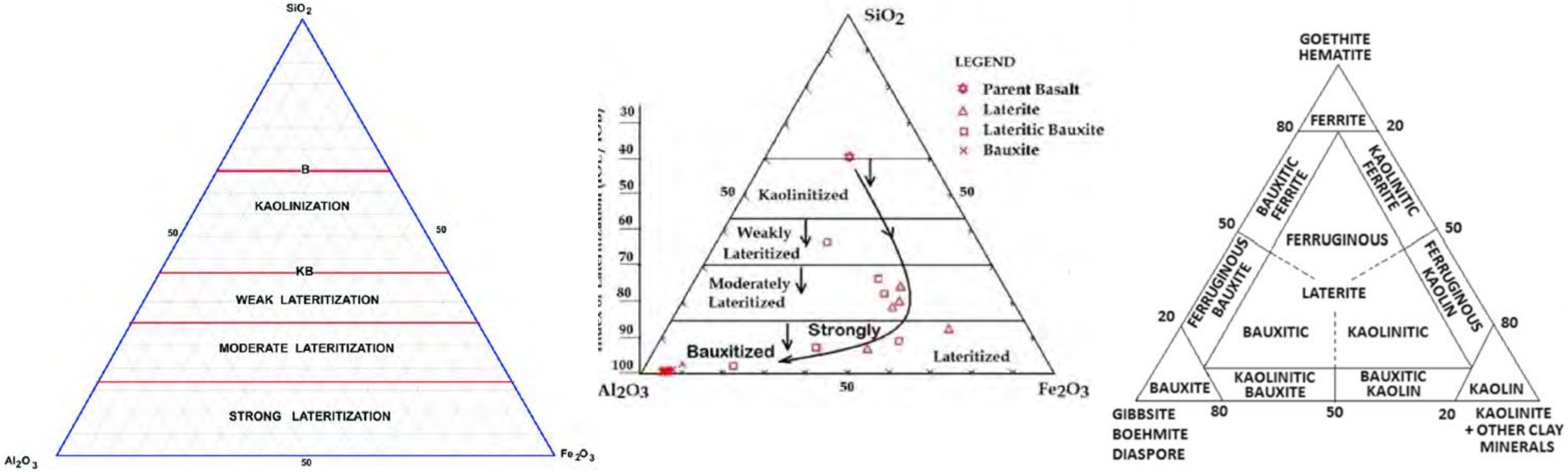
Journées Scientifiques :
"Bauxite Résidues"
Aix-en-Provence, du 08 au 09 juin 2021

Lateritic bauxites

Third largest producer of bauxite in the world, with a third of the world's proven reserves, the red ore from the Boké region attracts Australians, British, Emiratis, French, Indians, Russians and above all… the Chinese.

Lateritization

Under warm, wet conditions, Fe and Al become concentrated as other minerals are slowly leached out of the soil. Goethite (FeOOH) is one of the least soluble minerals formed during chemical weathering and forms an iron-rich crust, or ferricrete, at the surface. The lower horizons are rich in kaolinite. Between the red, iron-rich zone at the surface and the pale, clay-rich zone is a mottled zone where leaching has been concentrated in certain places. The sequence of ferricrete - mottled zone - pallid zone is called a laterite.



Ternary compositional diagram, illustrating the nomenclature of weathering products in humid tropical climates (after Valeton, 1972; Schellman, 1981,1986; Bárdossy and Aleva, 1990; Aleva, 1994)

The formation of lateritic bauxite requires a set of favorable conditions that include climate, time, hydrogeology, parent rock composition, geomorphology, petrophysics and biological factors (Aleva, 1984; Bárdossy and Aleva, 1990; Tardy, 1997; Bogatyrev *et al.*, 2009).
Key requisites are:

- *Wet tropical and subtropical conditions* with mean annual temperature above 20oC and rainfall above 1200 mm/yr, is the reason why many Cretaceous and Tertiary lateritic bauxite deposits in South America, Africa, India and Australia are found in (paleo-)coastal plains where humidity is usually higher than in continental interiors.

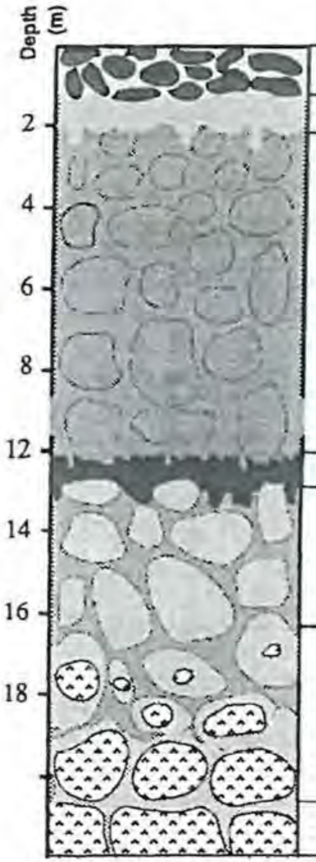
- *Parent rock with suitable composition* (e.g., Al O -content ≥ 10%, SiO -content is variable but preferably quartz-free) and sufficient porosity and permeability to allow fluids to percolate, leach out and transport dissolvable components.

- *Long-term tectonic stability* with quiet vertical uplifts as the only disturbance, favoring the formation of an elevated fault-dissected landscape with well-drained flat areas such as plateaus or peneplains (planation surfaces), since mature bauxite deposits mainly develop when the chemical weathering rate is higher than the rate of mechanical erosion. Passive continental margins often fulfill this requirement.

- *Favorable pH and Eh gradients* that allow fluid-rock interactions involving mineral dissolution and precipitation. Vegetation and metabolic products of micro-organisms may provide the acidity needed to accelerate the decomposition of aluminosilicate minerals (pH < 5), whereas new aluminum phases precipitate at pH 5.5–8.0. Likewise, the oxidation state of the system exerts a strong control on the (im-)mobility of Fe.

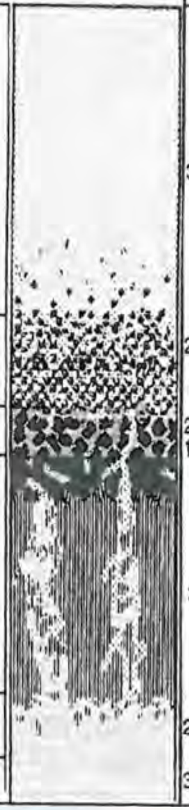
After Boulangé, Ambrosi and Nahon (1997)

Sketch of the chemical evolution during the original bauxite development from a granite weathering (mount Tato, Ivory Coast)



	SiO_2 l	SiO_2 c	Al_2O_3	Fe_2O_3	TiO_2
fragmentary bauxite	0.60	3.00	55.70	9.61	0.90
upper massive bauxite	0.10	2.40	61.10	4.60	0.56
lower massive bauxite	1.50	3.10	57.30	7.93	0.89
ferruginous layer	8.80	5.20	43.40	17.05	1.07
upper isalterite	9.00	14.30	43.20	9.70	0.92
lower isalterite	20.40	16.50	36.50	7.00	0.75
	21.00	25.10	35.60	2.40	0.25
	25.50	30.00	30.60	1.70	0.15
	33.00	37.40	16.90	1.00	0.10
Granite	29.30	39.80	16.60	2.78	0.31

Sketch of the chemical evolution of a lateritic bauxite on sediments (Porto Trombetas, Amazonia, Brazil)

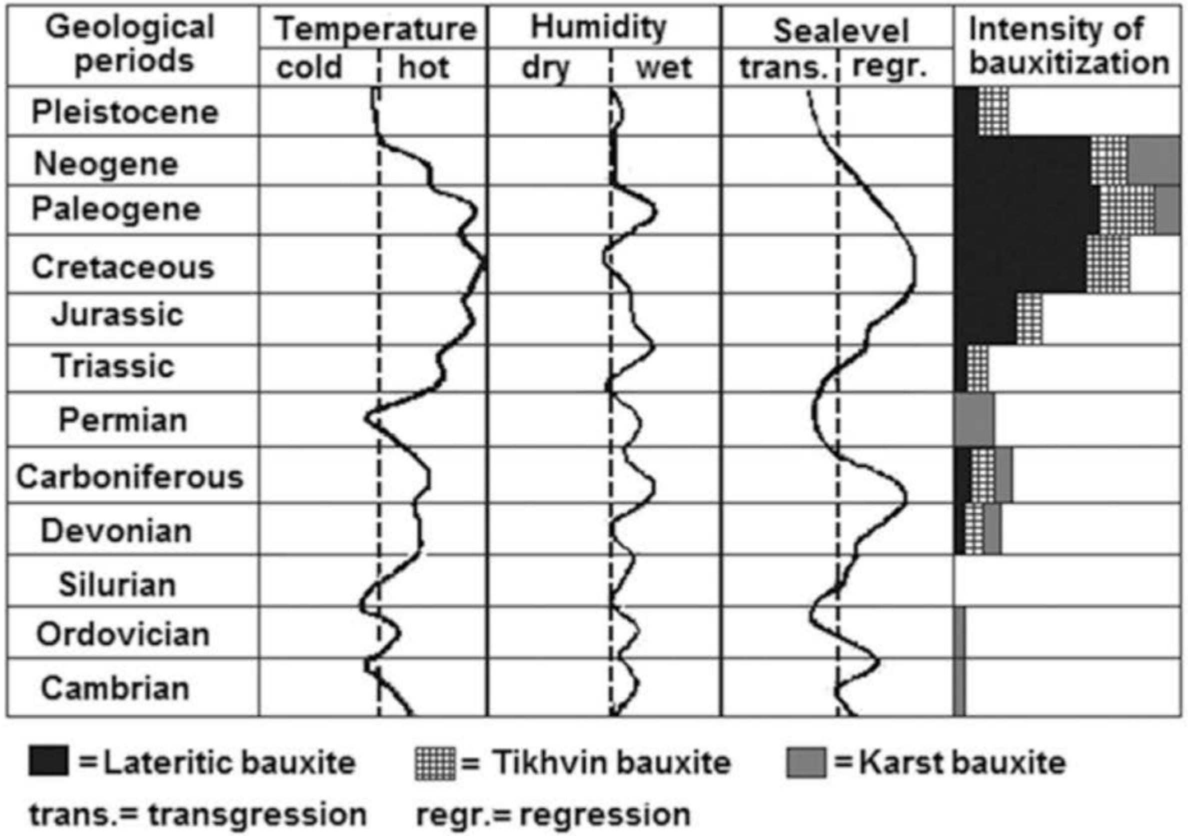


LAYERS		SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	Zr ppm
CLAY SANDY KAOLINITIC HORIZON		36.62	36.61	8.25	2.77	1518
NODULAR BAUXITE	matrix	26.20	43.35	8.30	2.25	1400
	Al nod.	4.30	61.20	2.20	1.10	640
FERRUGINOUS NODULES	matrix	22.80	29.00	31.10	2.20	1240
	Fe nod.	12.85	22.70	47.95	0.89	710
BAUXITE		1.37	53.80	15.25	0.80	430
		3.89	57.90	6.60	1.36	553
KAOLINITIC HORIZON		28.63	40.37	10.23	2.57	1033
SEDIMENT		39.87	36.65	7.92	0.70	215

The welcome sign to the MRN mining company town of Porto Trombetas stresses quality of life and safety above all else. Image by Thais Borges.

from Joáo Peres & Moriti Neto

Relationship between bauxitization, climate conditions and sea-level changes during Phanerozoic times (after Bogatyrev et al., 2009, Monsels, 2018).



Certain periods in the Earth's history were clearly more favorable for bauxite formation than others, as is demonstrated by the strong link with climate conditions and regressions. A productive period was the Cretaceous–Eocene epoch when bauxite formed in Gondwana and Laurasia.

Mineable bauxite contains mainly "hydrated alumina", 10-20% iron oxyhydroxide and about 5% silica. The contents are generally **48 to 58% in Al_2O_3** mainly in the form of gibbsite (“hydrargillite”) or boehmite in laterites and boehmite or diaspore (oxi-hydroxide in karst bauxites).

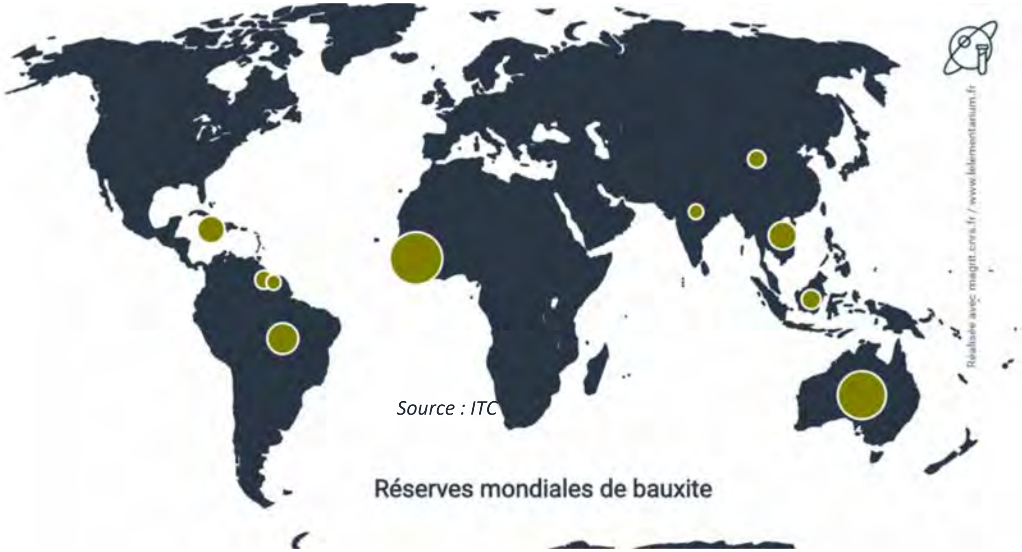
Bauxites contain a low content of 30 to 80 ppm gallium and are the main source of this element. For example, in 2019, with a production of 17.605 million t of alumina, the Chinese group “Chalco” co-produced 98 t of gallium.

☞ In Russia, Siberia and the Kola Peninsula, ores rich in nepheline ($2SiO_2$, Al_2O_3, Na_2O-K_2O) are also exploited, recovered as by-products of the extraction of apatite intended for the phosphate fertilizer industry and also ores rich in alunite (K_2SO_4, $Al_2(SO_4)_3$,$4Al(OH)_3$) are mined. In 2019, the UC Rusal group's nepheline production in Siberia at Kiya Shaltyr was 4.244 million t.

Australie	105 176	En milliers de t. de bauxite	Indonésie	16 593
Guinée	70 173		Jamaïque	9 022
Chine	68 400		Russie	5 572
Brésil	31 938		Arabie Saoudite	4 781
Inde	22 307		Kazakhstan	3 812

Source : ITC

Source : « Commodity markets outlook », World Bank, oct. 2020



Guinée	7 400	En millions de t. de bauxite	Indonésie	1 200
Australie	6 000		Chine	1 000
Vietnam	3 700		Guyana	850
Brésil	2 600		Inde	660
Jamaïque	2 000	*Source : USGC*	Russie	500

Chine	100 665	En milliers de t. de bauxite	Émirats Arabes Unis	3 236
États-Unis	4 991		Allemagne	2 550
Irlande	4 730		Inde	2 472
Espagne	4 159		Roumanie	1 545
Canada	3 680		Ukraine	1 443

Guinée	60 549	En milliers de t. de bauxite	Guyana	2 060
Australie	39 759		Sierra Leone	1 696
Indonésie	15 500		Turquie	1 457
Brésil	7 105		Iles Salomon	1 234
Jamaïque	3 036		Inde	1 208

Production of alumina

Explosion à Gardanne
le 31 mai 1932 :

In 2017, there were 80 refineries around the world.
In China, the number increased from 7 factories in 2001 to 49 factories in 2011.

In the European Union, in 2019 there were 7 alumina production plants, including one in each of the following countries:

- France, in Gardanne (13) operated by Alteo with 635 000 t/y,
- Germany, in Stade, operated by Dadco with a capacity of 1 million de t/y,
- Spain in San Ciprian, operated by AWAC avec 1,595 million de t, in 2019,
- Ireland, in Anghinish, operated by UC Rusal with 1,893 million de t in 2019,
- Greece, in Distomon operated by Mytilineos with 820 100 t, in 2019,
- Hungary, in Ajka operated by MAL Magyar, (unknow production)
- Romania, in Tulcea, operated by Alum, a subsidiary of the Vitmeco group, with 460,911 t in 2019. The refinery is supplied with bauxite from the Sierra Leone mine

Stockage de boues rouges à Stade, Allemagne

Rupture d'un réservoir de boues résiduelles en Hongrie, le 4 octobre 2010

Bauxite processing residues ("red muds or sludges") represent 0.7 to 2 t / t of alumina, or, worldwide 182 million t / year.
In total, since the operation of the Bayer process, this represents 3 billion t of bauxite processing residues

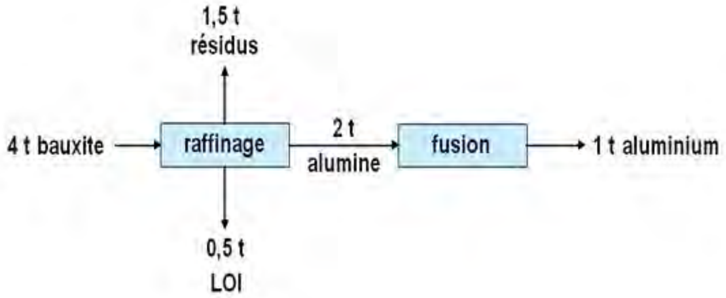
Composition range of bauxite processing residues:

Sources : IAI et EAA

Fe_2O_3	20 à 45 %	CaO	0 à 14 %
Al_2O_3	10 à 22 %	SiO_2	5 à 30 %
TiO_2	4 à 20 %	Na_2O	2 à 8 %

To produce 1.9 t of Al2O3 which gives 1 t of Al by electrolysis in molten salt, it is needed:

Bauxite	4 à 5 t	Lime	200 kg	Energy : 380 kWh
Water	13,5 t	NaOH	210 kg	



We distinguish:

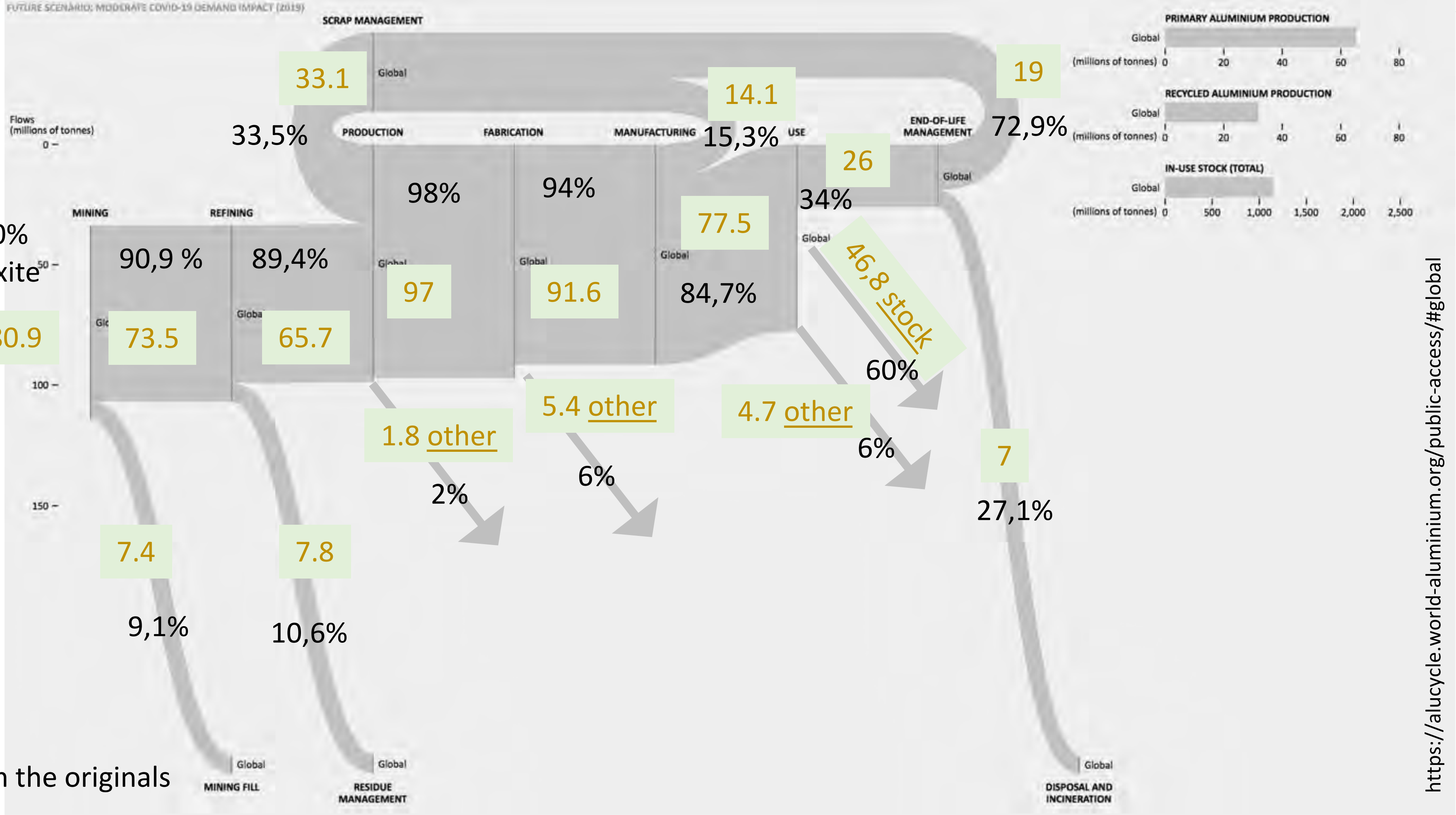
- "Hydrated alumina"
  - Aluminum hydroxides of the formula: $Al(OH)_3$ or $Al_2O_3.3H_2O$; bayerite, gibbsite, nordstrandite
  - Aluminum oxihydroxides of the formula: AlOOH or Al_2O_3, H_2O; boehmite and diaspore
- "Transition alumina": metastable Al_2O_3 varieties gamma, delta, theta…. kappa
- Alpha alumina or corundum: Al2O3 (T> 1200 ° C) "calcined alumina"
- "Molten alumina" or white corundum (melting 2100 ° C)
  [we can also cite brown corundum]

GLOBAL ALUMINIUM CYCLE 2020

Mine de bauxite et usine de traitement à Kamsar, au nord de Conakry, capitale de la République de Guinée.

WORLD ALUMINIUM

Mine en Guinée



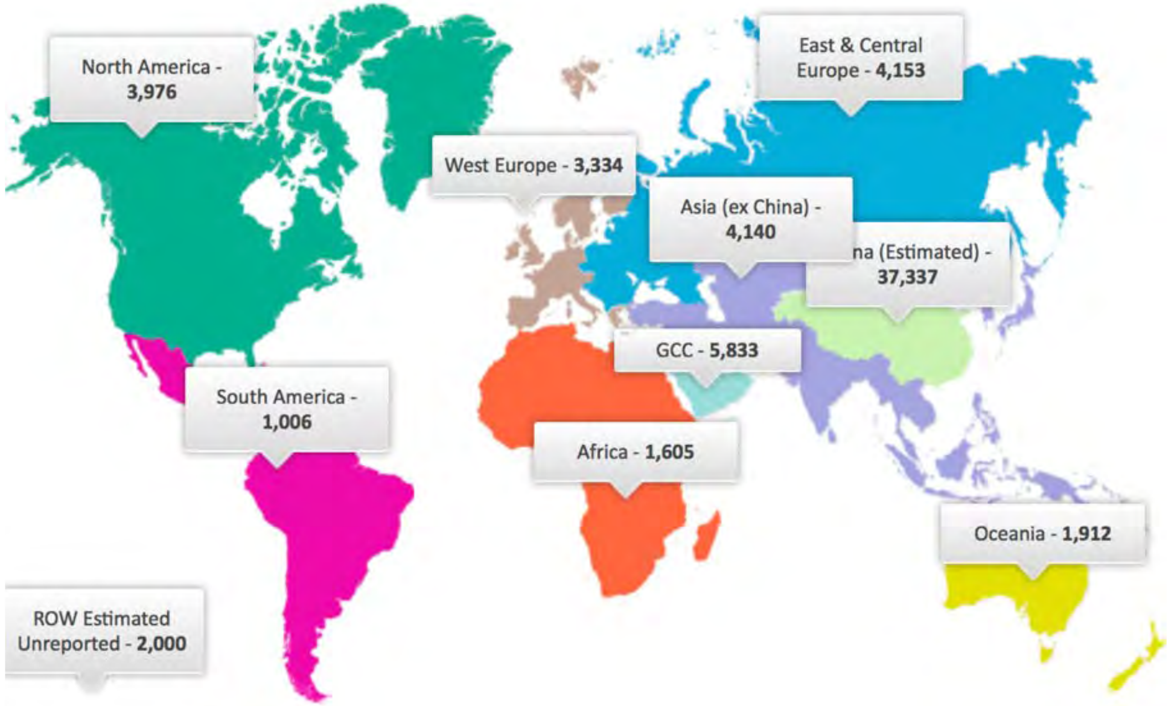
Numbers are rounded off from the originals

https://alucycle.world-aluminium.org/public-access/#global

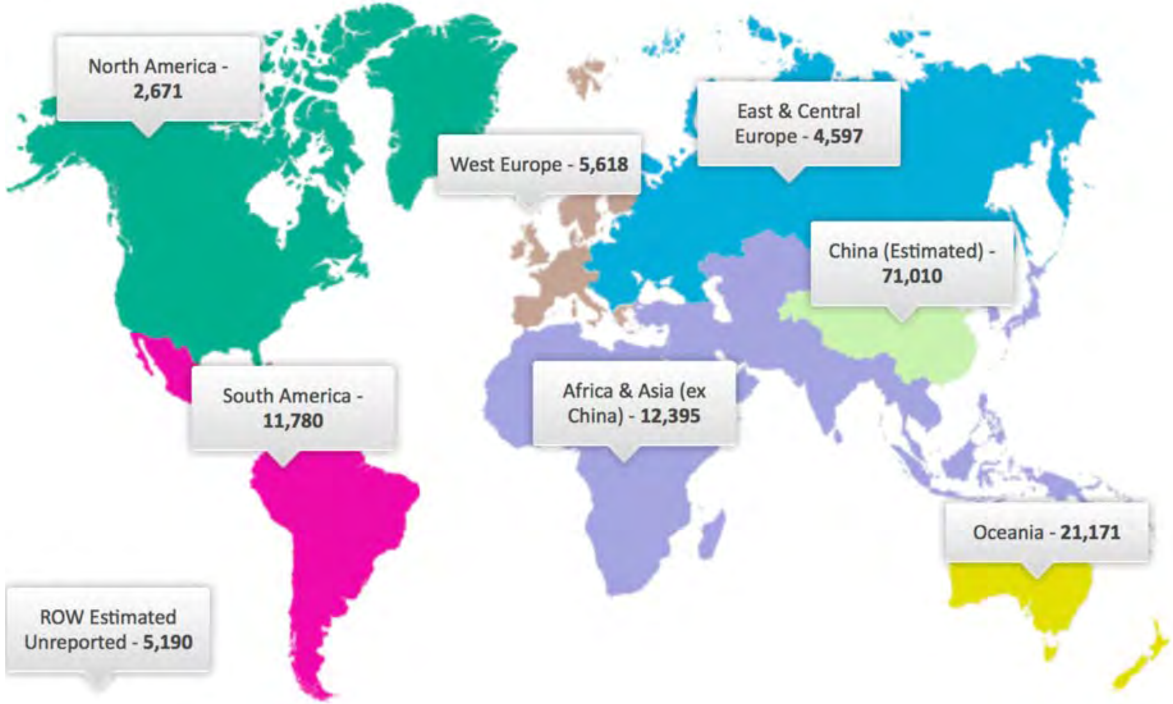
Journées Scientifiques :
"Bauxite Résidues"
Aix-en-Provence, du 08 au 09 juin 2021

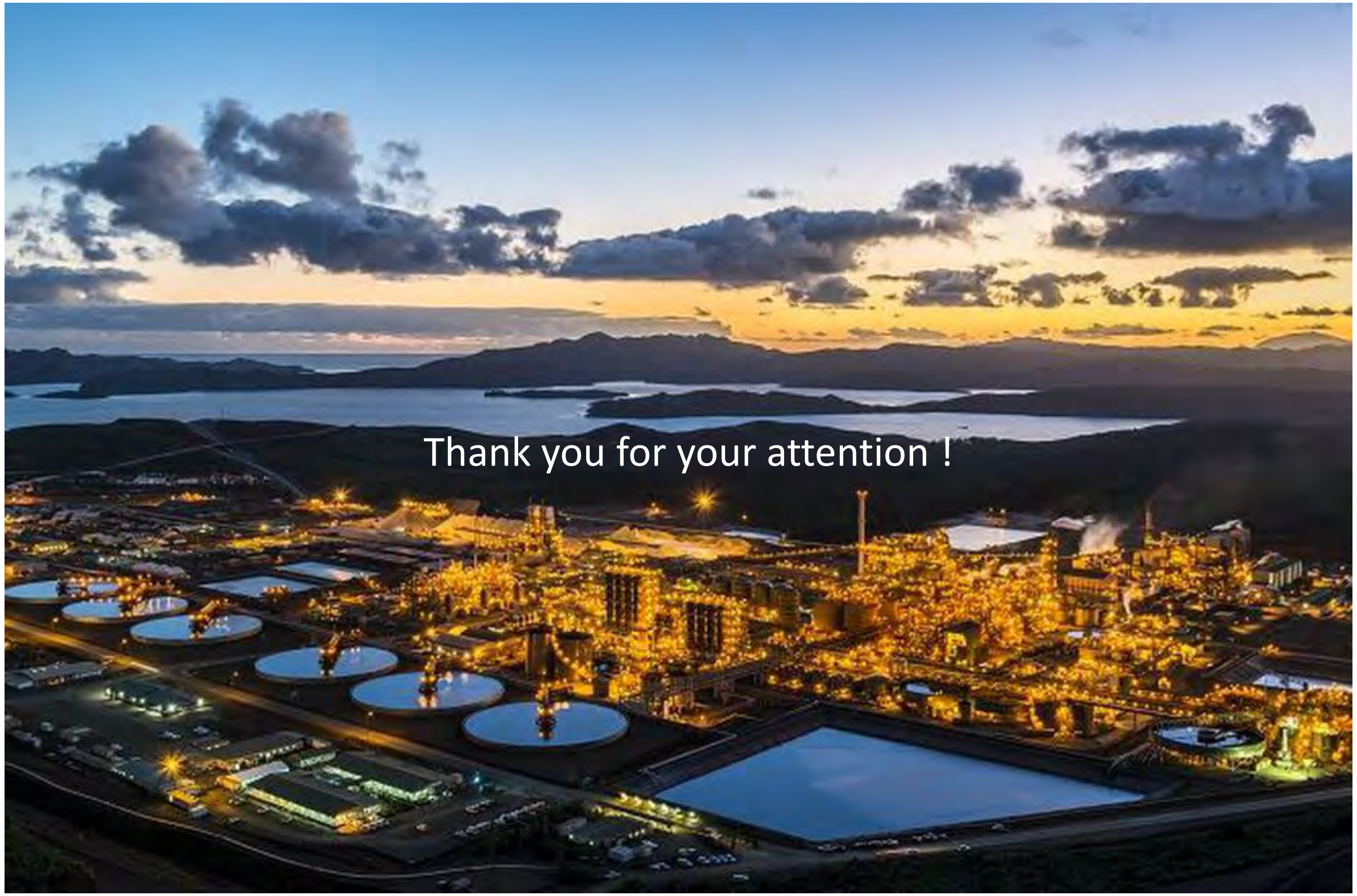
INTERNATIONAL ALUMINIUM

Total for 2020: 65,296 thousand metric tonnes of aluminium



Total for 2020: 134,432 thousand metric tonnes of alumina (total)




Thank you for your attention !