ALUMINUM IN IBEROAMERICA: MINERAL DEPOSITS AND MINING PRODUCTION

ARGENTINA

Report prepared by Servicio Geológico Minero Argentino for the Metallogenetic Expert Group of ASGMI (Asociación de Servicios de Geologia y Minería Iberoamericanos)

SegemAR Servicio Geológico Minero Argentino

ASGMI Asociación de Servicios de Geología y Minería Iberoamericanos

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1. Introduction

Argentina is a country located in the southernmost portion of the american continent, to the east of the Andes Cordillera. Argentina`s territory covers a surface of about 2.8 million squere kilometers of South America and reachs almost 3.8 million squaqre kilometers with the adding of its sovereign claims over the territories of the Antarctic Continent and South Atlantic islands (Figure 1).

Figure 1: Map of the Argentine Republic territories. Dark Green: South American continental territory. Light Green: Antarctic and South Atlantic Islands Territories. (extracted from Wikipedia, 2020)

Although Argentina has abundant mineral resources (with mines of Cu, Ag/Pb/Zn, Li, Au, Sb, Mn, U, K, borates, barite, sodium sulfate and halite related to the Andes Cordillera, Au-Ag, Fe and bentonites deposits in the Patagonia and dimension stone quarries in the Pampean Ranges), the country never had its own aluminum production. Notwithstanding Argentina has an important factory of aluminum products (ALUAR), wich produces up to 460,000 tonnes of aluminum per year, consuming in the process 850.000 tonnes of alumina (Aluar, 2020). A 30% of this facility production (bars, plates, wires, industrial profiles, sheets and aluminum carpentry systems among others) is sell to the argentinian market, the othter 70% is exported to countries like the United States, Brazil, Japan, Germany and others (Aluar, 2020). Bauxite is the source for alumina and the most important commodity for the ALUAR industrial process. It is entirely imported.

The predecessors of the argentinian geological and mining service (SEGEMAR) carried out several investigations in order to find aluminum deposits within the argentinian territory. In the year 1947, Pascual Sgrosso, geologist of the Economic Geology Department elaborated a Project to extract aluminun from kaolyn deposits. Later de National Direction of Geology and Mining made a compilation of all the aluminun rich rock or deposits known at that time (Oliveri, 1954). In the 1960`s and 1970`s the National Institute of Geology and Mining and the Ministery of Industry and Mining explored the lateritic deposits of Misiones Province serching for Bauxites (Valania, 1968, 1974). Alunite deposits of the Patagonia were also explored in those decades (Sister and Klein, 1952; Anselmino, 1967; Camacho, 1971). Since none economically exploitable deposit was found, aluminum prospecting in Argentina was cancelled since the 1980`s until now.

Nowadays the development of new extraction techniques from non-traditional aluminum ores, specially from anorthosites, have brought a renewed interest in aluminum rich deposits. With that in mind SEGEMAR elaborated this report, compiling all the mentionend old research studies and new ones from deposits previously not taken in account as aluminum sources.

2. Geological setting

The western portion of Argentina is under the influence of andean tectonics. The country shares with Chile and Bolivia Republics the southern part of the Central Andes, including the Puna Plateu, and with Chile, the Southern Andes. Along this portion of the Andes Cordillera altitudes over 3000 masl are frequent, including several peaks higher than 6000 masl. The elevation of the cordillera folded and exposed basement rocks of neoproterozoic age in the northern and southern part of the country, and of Mesoproterozoic age in the central portion of Argentinian Andes. Paleozoic marine deposits, intruded by coeval plutons, are common. They underlay continental and marine successions with volcanic intercalations of Mesozoic and Paleogene age. Neogene arc and back arc volcanism affected all the mountain chain.

The central east and north-east sides of the country are mostly occupied by the Pampean and Chaco-Pampean Plains. These plains are covered by quaternary continental deposits with the exception of two Proterozoic Ranges in Buenos Aires Province and the basaltic mesozoic plateau in Misiones and Corrientes Provinces.

The southeast portion of the country is integrated by the Patagonic Plateau, a desert region bounded to the east by the Atlantic Ocean. Two igneus plateaus are the mean features of this region. The Somuncura Massif to the north, and the Deseado Massif in the south. Both of them are integrated mostly by Mesozoic to Cenozoic volcanites interbedded with continental and marine sediments.

3. Mineral deposits of aluminium

The Argentine Republic doesn´t have or had aluminum mines nor aluminum extraction as a subproduct of other metallurgical process. This is due to lack of known bauxite deposits within its territory and to the fact that other possible aluminum sources were considered uneconomical. Nevertheless Argentina possess different tipes of rocks and mineral deposits that, in consideration of its alumina content, may become economical sources for aluminum extraction with the arising of new metallurgical technologies. After a exhaustive bibliographic research five potential aluminum deposit types, whit alumina contents greater than 20% of the bulk rock, were identified:

1- Lateritic soils of the province of Misiones: residual deposits enriched of Fe and Al by chemical weathering of basaltic rocks at the Misiones jungle, northeastern Argentina.
2- Anorthosites: proterozoic ultrabasic massif constituded mainly by plagioclase (calcium-sodium aluminosilicates). They outcrop in the precordillera of La Rioja and San Juan provinces, in the middle west of Argentina
3- Kaolin: Deposits of this aluminum rich clay mineral generated by alteration processes of igneous rocks or by sedimentary accumulation. Deposits of this type are found in several argentine provinces, mainly related to the cordillera and the Patagonia, from Jujuy in the north to Santa Cruz in the south.
4- Cordieritite: an unusual rock formation segregated by aluminum rich magmas resulting from the partial melting of pelitic rocks. There is only one known deposit in Argentina, it is located in province of Cordoba.
5- Alunite: aluminum and potassium sulphate formed by the alteration of volcanics rocks under special conditions. Theres is only one deposit of economic volume in Argentina and it is located in the east of the province of Chubut, in the Patagonia.

The more important characteristics, aluminia content, tonnage (if known), and probable genesis of these deposits are listed below.

1) **<u>Laterites of the Province of Misiones</u>**:

The province of Misiones, located at the northeast corner of the Argentine Republic, is well known by the presence of red lateritic soils. These soils are developed over the toleitic Serra Geral Basalts, wich constitute one of the largest basaltics provinces of the world, extending over a surface of 1.2 million square kilometers of Argentina, Brazil, Uruguay and Paraguay (Figure 2), with a thickness oscillating between 800 and 1930 meters (Madsen et al, 2018). The age of the basalts varies between 160 Ma for the oldests, and 115Ma for the youngests (Fodor et al, 1989). The mineral composition comprehends labradorite, augite/ titaniferous augite and opaque mineral phenochrysts immersed in a paste conformed by bytownite, augite, apatite and volcanic glass in different proportions (Madsen et al, 2018). The chemical composition of basalt samples assayed by Madsen et al. (2018) are presented in table 1:

Muestra	Mayoritarios							Minoritarios			LOI
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	
1S	50,12	12,46	15,52	4,38	8,35	2,68	1,45	0,22	3,53	0,39	0,5
1M	49,75	12,26	16,23	4,38	8,20	2,66	1,43	0,20	3,50	0,38	0,7
1I	49,74	12,24	16,13	4,48	8,26	2,64	1,42	0,22	3,52	0,38	0,6
2I	49,66	11,89	16,22	4,77	8,76	2,30	1,27	0,20	3,14	0,39	1,0
2M	49,48	11,61	16,28	4,77	8,55	2,31	1,24	0,21	3,18	0,37	1,6
2S	49,63	11,79	16,60	4,42	8,66	2,32	1,24	0,20	3,24	0,36	1,2
3I	54,42	12,56	14,53	3,44	7,03	2,91	1,84	0,20	1,81	0,24	0,7
3M	54,94	12,74	14,00	3,39	6,92	2,97	1,81	0,24	1,82	0,24	0,6
3S	55,06	12,32	14,56	2,74	6,14	3,09	2,09	0,19	1,94	0,29	1,3
4I	50,03	12,24	16,13	4,29	8,26	2,64	1,44	0,21	3,50	0,39	0,5
4M	49,75	12,16	16,27	4,38	8,34	2,61	1,41	0,22	3,48	0,37	0,6
4S	49,78	12,32	15,91	4,35	8,32	2,62	1,42	0,21	3,49	0,38	0,8
5I	52,57	13,67	12,29	5,22	8,82	2,62	1,30	0,17	1,35	0,16	1,5
5M	51,45	14,14	11,91	4,85	8,69	2,63	1,42	0,15	1,40	0,17	2,9
5S	49,333	13,66	12,37	5,36	8,19	2,31	1,05	0,15	1,28	0,16	5,7

Table 1. Assay results of 15 basalts samples of the province of Corrientes (Madsen et al, 2018).

Geochemical studies realized by Campodónico et al (2019) show that Misiones laterites are the result of in situ chemical weathering of Serra Geral Basalts. The present humid climate, (subtropical without dry season, with 21ºC of mean annual temperature and rainfalls between 1700 and 2000 mm per year) is favorable for the development of latericts soils. The lateritic sheet has up to several meters in thickness and that is the one of the reasons why, in the decades of 1960´s and 1970´s, prospection campaigns were carried on at Misiones province. The goal of this campaigns was to find natural aluminum, iron and titanium concentrations as result of the leaching of basalts during the formation of red soils. The main outcome of the prospection was the discovery of Puerto Peninsula deposit, a lateritic bed containing inferred resources of 1409 million tonnes with grades of 12,4% Al, 13,5% Fe and 2.34% Ti (Valania, 1968).

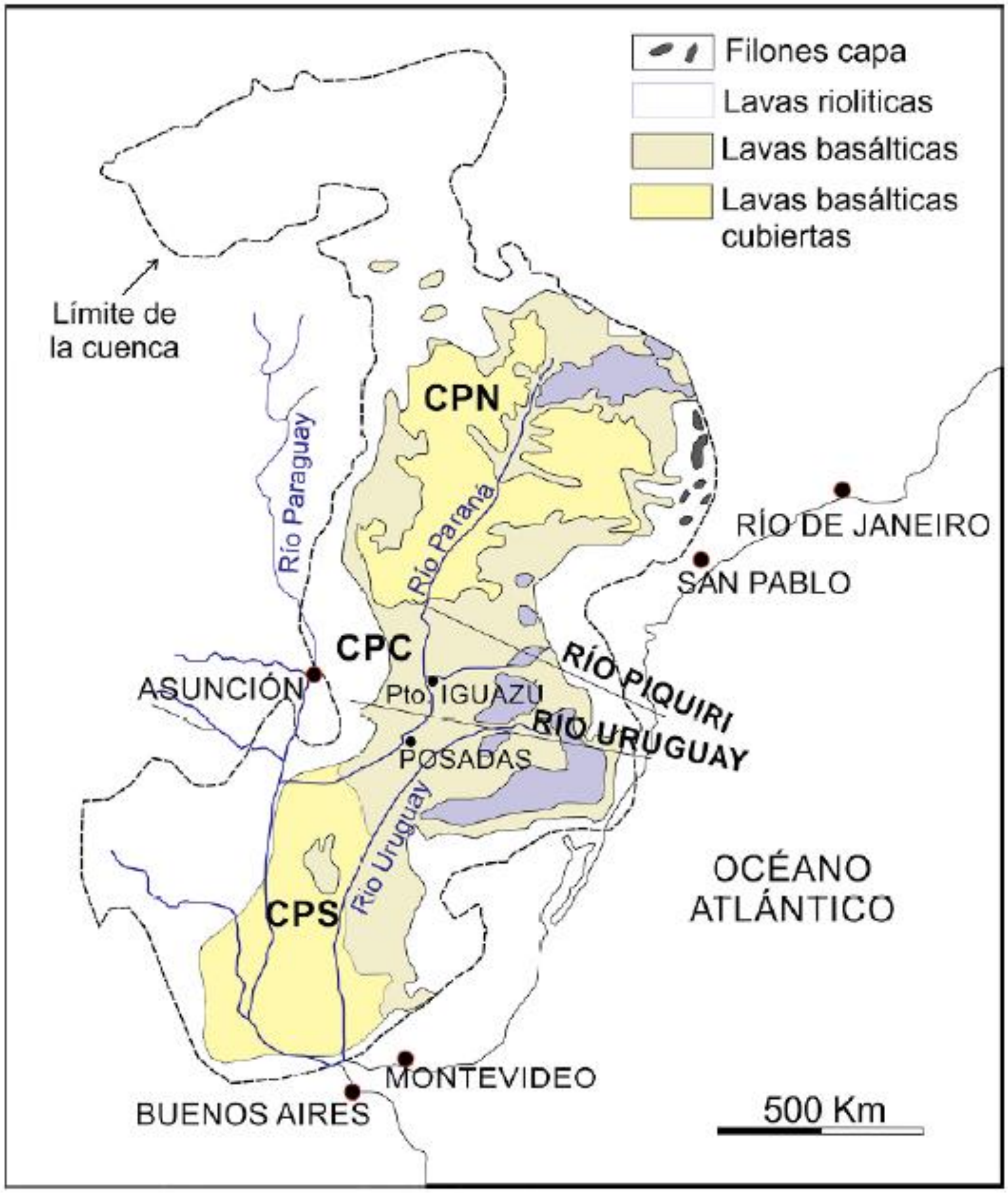

Figure 2. Reconstruction of the área covered by the Serra Geral basaltic magmatism in South America. Taken from Peate (1997) Regions established by Piccirillo et al (1988) are shown. CPS: South Parana Basin, CPC: Central Parana Basin and CPN: North Parana Basin.

381930 tonnes of these laterites were extracted between 1975 and 1981 for the production of aluminum and iron sulphates (Angelelli, 1985). The data obtained during the exploration of this soils (Valania, 1968) is the following:

Entre 1975 y 1981 se explotaron 381930 toneladas utilizadas para la producción de sulfatos de aluminio y hierro (Angelelli, 1984). Los datos de las muestras obtenidas de estos suelos (Valania, 1968) son los siguientes (table 2):

Muestra Nº	Nivel	Profundidad m	Pérdida	SiO_2 / Al_2O_3	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	CaO %	MgO %	Na_2O %	K_2O %	
P.1	A	0-3.20		1.2	42.0	35.8	13.2	1.6	-	-	-	-	Rojo, plástico, deleznable, homogeneo
	B	3.20-3.45		2.5	47.5	18.8	15.2	4.0	-	-	-	-	Rojo-amar., magro, delez., restos basalt.
	C	+ de 3.45		4.1	44.6	10.8	21.2	3.6	-	-	-	-	Basalto semialterado
P.2	A	0-1.60		2.2	48.1	21.5	15.6	3.4	-	-	-	-	Rojo,plástico, deleznable, homogeneo
	B	1.60-2.20		2.3	48.0	20.4	16.8	4.0	-	-	-	-	Violáceo, magro, delez., Restos Basalto.
P.3	A	0-7.30		1.1	35.6	33.7	16.4	1.6	-	-	-	-	Rojo, plástico, deleznable, homogeneo
	B	7.30-8.10		1.4	35.2	23.5	22.0	4.0	-	-	-	-	Amarillenta magra, manchas viol.y blancas deleznable
P.4	A	0-6.05		2.1	40.3	19.3	19.2	4.4	-	-	-	-	Rojo, plástico, deleznable, homogeneo
	B	6.05-6.50		2.1	38.3	18.4	21.6	4.4	-	-	-	-	Amar.-viol., Restos basalto semialterado
P.5	A	0-0.65	11.0	5.6	47.2	8.4	27.6	5.6	V.	0.6	V.	V.	Amarillento, pocoplástico, deleznable
	B	0.65-1.90	13.1	2.6	53.1	20.2	8.0	5.8	V.	0.5	V.	V.	Aluvion,Arcilloso, manchas limon. y hemat.
	C	1.90-4.30	12.4	3.4	48.3	14.0	16.0	4.4	V.	0.5	V.	V.	Aluvion,Arcilloso, rojo-amarillento
	D	4.30-8.50	14.0	2.4	50.5	20.6	10.8	4.0	V.	0.6	V.	V.	Aluvion,Arcilloso, muy plast., amarillento
	E	8.30-9.15	13.8	2.4	51.1	20.9	8.4	4.6	V.	0.8	V.	V.	Aluvion,Arcilloso, muy plast., grisáceo
	F	9.15-9.50	19.1	2.6	40.9	15.6	20.4	4.0	V.	0.8	V.	V.	Amar.magra, arena basáltica incluida
P.6	A	0-1.15		1.6	42.4	25.0	12.4	4.2	-	-	-	-	Rojo obscuro, mat.orgánica incluida
	B	1.15-7.25		1.2	42.7	24.5	14.4	3.0	-	-	-	-	Rojo, plástico, delez., homogéneo
	C	7.25-8.20		1.6	36.9	22.4	23.6	4.0	-	-	-	-	Idem, fragment. basálticos incluídos
P.7	A	0-1.60		4.0	50.1	12.5	17.6	5.0	-	-	-	-	Rojo,plástico,deleznable, homogeneo
	B	1.60-2.40		4.1	47.4	11.3	21.6	8.8	-	-	-	-	Idem, castaño-amarillento
	C	2.40-3.00		3.7	48.5	12.9	21.2	5.8	-	-	-	-	Amarillento, semiplast., fragm. basalto
P.8	A	0.10-2.30	12.2	4.2	56.9	13.4	10.8	5.2	V.	0.5	V.	V.	Aluvion, arcilloso, castaño, homogeneo
	B	2.30-4.50	12.8	2.9	50.4	17.0	14.0	5.0	V.	1.5	V.	0.1	Aluvion, arcilloso, amarillento, homogeneo
	C	4.50-6.00	12.9	4.5	56.8	12.5	16.0	2.0	V.	0.4	V.	V.	Aluvion, arcilloso, grisáceo, homogéneo
	D	6.00-6.40	13.1	1.7	41.6	24.0	18.0	3.2	V.	0.4	V.	V.	Idem, rojizo, fragmentos basálticos
P.9	A	0-3.60		1.4	36.3	25.5	16.4	2.6	-	-	-	-	Rojo, plástico, deleznable, homogéneo
	B	3.60-5.90		1.4	30.8	21.4	22.8	3.8	-	-	-	-	Idem con arena basalt. manchas amari-verd.
	C	5.90-7.80		1.4	32.7	23.3	24.4	4.6	-	-	-	-	Amar.-gris., magro, arena, manch.Negras,limon
P.10	A	0-5.55		1.5	40.2	25.2	18.8	4.2	-	-	-	-	Rojo,plastico,deleznable, homogéneo
	B	5.55-9.40		1.4	33.0	23.5	20.4	4.8	-	-	-	-	Idem con vetillas limoníticas y hematíticas
	C	9.40-9.70		1.3	32.4	24.2	26.0	5.3	-	-	-	-	Idem, negruzco, manchas limoníticas

Muestra Nº	Nivel	Profundidad m	Pérdida	SiO_2 / Al_2O_3	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_3 %	CaO %	MgO %	Na_2O %	K_2O %	
P.11	A	0-1.30		2.3	48.2	20.1	16.0	4.0	-	-	-	-	Rojo-amar., magro, fragment. basálticos
	B	1.30-1.50		3.1	42.2	13.3	28.4	5.3	-	-	-	-	Idem, amarillento, fragment. basalt.mayores
P.12	A	0-7.88		1.6	38.2	22.7	20.8	4.3	-	-	-	-	Rojo, plástico, deleznable, homogéneo
	B	7.88-9.89		1.4	33.3	23.2	24.0	4.2	-	-	-	-	Idem, amarillento, fragmentos basálticos
P.13	A	0-3.85	10.2	1.5	40.0	25.6	21.2	2.8	V.	0.4	V.	V.	Rojo, plástico, deleznable, homogeneo
	B	3.85-7.02	10.3	1.3	33.7	25.7	26.0	4.2	V.	0.3	V.	V.	Castaño, magro, manchas amar.-blancas
	C	7.02-9.50	10.3	1.2	34.5	27.7	26.0	3.8	V.	0.3	V.	V.	Idem, menos magra, puntos blancos
	D	9.50-10.40	10.8	1.4	35.3	24.3	26.0	3.8	V.	0.3	V.	V.	Morado, manchas blancas
P.14	A	0-4.18		1.6	41.9	25.0	19.2	2.0	-	-	-	-	Rojo, plástico, deleznable, homogéneo
	B	4.18-7.80		2.1	49.5	23.1	22.0	2.2	-	-	-	-	Castaño-amar., magra, deleznable
	C	7.80-9.20		1.9	39.6	20.2	23.6	2.4	-	-	-	-	Idem, amarillo
P.15	A	0-0.55		4.8	53.0	11.0	22.4	3.2	-	-	-	-	Aluvión, arcilloso, gris, manchas rojas
	B	0.55-1.30		2.4	41.0	16.8	20.8	6.0	-	-	-	-	Idem, rojizo, fragmant. basálticos alterado
P.16	A	0-1.60		3.3	52.8	15.8	16.8	4.3	-	-	-	-	Rojo, plástico, deleznable, homogéneo
	B	1.60-3.10		2.6	44.7	16.7	22.0	4.0	-	-	-	-	Anaranjado, magro, manchas limon.,fragm.basal.
P.17	A	0-2.40	13.0	1.6	38.7	23.0	20.4	5.0	V.	0.5	V.	V.	Rojo, plástico, deleznable, homogéneo
	B	2.40-3.20	13.4	2.2	40.8	18.4	25.6	2.0	V.	0.3	V.	V.	Idem, castaño-anaranjado
	C	3.20-4.16	10.1	1.4	34.7	24.9	27.2	3.0	V.	0.8	V.	V.	Castaño-amar., magro, fragmt.basalt.alt.
	D	4.16-5.12	13.2	1.9	36.0	18.7	26.8	3.0	V.	0.5	V.	V.	Idem, amarillento
	E	5.12-6.00	13.8	1.4	32.8	23.1	24.8	4.0	V.	0.5	V.	V.	Idem, muy magro
	F	6.00-7.75	13.9	1.5	33.7	21.3	26.4	4.4	V.	0.3	V.	V.	Idem, rojizo
P.19	A	0-6.55		2.5	52.3	20.8	14.0	2.0	-	-	-	-	Rojo, plástico, deleznable, homogeneo
	B	6.55-7.10		4.2	58.0	13.7	16.4	2.4	-	-	-	-	Aluvional, arcilloso, muy plast., amarillento
P.20	A	0-1.10		10.7	74.2	6.9	8.0	3.4	-	-	-	-	Aluvión, arcilloso,muy plástico,amarillento
	B	1.10-1.40		14.2	81.3	5.7	4.6	3.8	-	-	-	-	Aluvión, arcilloso, muy plástico, gris
P.21	A	0-3.90		3.8	51.9	13.4	17.2	4.0	-	-	-	-	Rojo, Plástico,deleznable,homogéneo
	B	3.90-4.62		2.5	44.9	17.6	19.6	2.4	-	-	-	-	Rojo, magro, manchas, limon. y negras, arena

Muestra Nº	Nivel	Profundidad m	Perdida	SiO_2 / Al_2O_3	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	CaO %	MgO %	Na_2O %	K_2O %	
P.22	A	0-1.85	-	1.9	58.8	30.9	12.0	6.0					Aluvión, arcilloso, gris, fragm.rojizos,arena
	B	1.85-2.30	-	2.2	37.8	17.1	30.0	3.0					Idem, con fragmentos de basalto
P.23	A	0-3.75	-	1.5	45.2	30.3	12.9	3.2					Rojo, plástico, deleznable, homogéneo
	B	3.75-7.20	-	1.3	36.3	28.3	24.0	4.4					Anaranj., magro, arenoso, manchas negras
	C	7.20-8.30	-	2.1	44.3	20.9	21.6	3.3					Idem, amar., puntos y manchas blancas y negras
P.24	A	0-4.60	-	1.5	39.7	25.6	20.4	3.3					Rojo, plástico, deleznable, homogéneo
	B	4.60-9.42	-	0.98	33.9	34.4	23.2	3.3					Idem, rojo-amarillento
P.25	A	0-2.40	-	1.5	41.9	28.9	18.0	3.3					Rojo, plástico, deleznable, homogéneo
	B	2.40-2.90	-	1.6	38.3	23.7	20.0	4.4					Idem, amarillento, manchas limoníticas
P.26	A	0-0.20	-	5.5	53.9	9.8	25.2	4.0					Aluvión, arcilloso, homogéneo, mat. org.
	B	0.20-2.30	-	7.2	65.4	9.0	12.0	3.2					Idem, amarillento, frag. basalto alterado
	C	2.30-3.20	-	1.9	42.5	21.7	22.0	4.4					Rojo, magro, puntos caolín y limon.
P.27	A	0-4.0	-	1.4	45.0	30.6	16.4	3.3					Rojo, plástico, deleznable, homogéneo
	B	4.0-4.9	-	1.6	36.9	23.3	20.4	4.4					Castaño-amar., magro puntos limonit.
	C	4.9-5.37	-	1.4	36.3	25.3	24.0	3.1					Idem, amarillento
P.28	A	0-8.45	-	1.4	36.0	26.4	23.2	4.2					Rojo, plástico, deleznable, homogéneo
	B	8.45-8.90	-	2.2	35.6	15.8	24.4	4.0					Rojo-amar., deleznable, manchas limoníticas
P.29	A	0-6.0	-	1.8	43.9	24.3	18.4	3.3					Rojo, plástico, deleznable, homogéneo
	B	6.0-6.61	-	2.7	53.1	19.7	12.0	6.4					Idem. naranja, manchas, limon, y hemat.
P.30	A	0-6.0	-	1.2	27.5	23.2	17.6	4.4					Rojo, plástico, deleznable, homogéneo
	B	6.0-7.26	-	2.2	44.3	19.9	19.6	5.5					Idem, amar., manchas gris, arenoso
P.31	A	0-4.0	-	1.4	32.6	23.8	22.4	4.4					Rojo, plástico, deleznable, homogéneo
	B	4.0-4.70	-	1.4	33.1	23.0	26.0	4.0					Rojo-amar., magro, manchas grisáceas
P.32	A	0-3.80	-	2.6	43.7	16.4	22.4	4.0					Rojo, plástico, deleznable, homogéneo
	B	3.80-8.40	-	5.1	50.5	9.9	22.0	3.6					Pardo, magro, deleznable, puntos blancos
P.44	A	0-3.50		1.3	38.3	28.5	19.2	4.0					Rojo, plástico, deleznable, homogéneo
	B	3.50-8.80		1.2	33.5	28.4	24.8	4.4					Amarillento, magro, manchas blancas
P.45	A	0-5.20		1.4	35.9	26.1	23.2	4.6					Rojo-amarillento, plástico
	B	5.20-9.40		1.4	33.1	24.1	26.0	3.2					Amarillento, magro, puntos y manchas blancas
P.46	A	0-3.50		1.5	34.2	22.3	24.8	4.4					Rojo, plástico, deleznable, homogéneo
	B	3.50-8.80		1.4	36.2	25.1	24.1	3.2					Amarillo, magro, manchas blanquecinas
P.47	A	0-7.70		3.6	50.5	14.0	19.6	6.6					Rojo, plástico, deleznable, homogéneo
	B	7.70-12.20		1.1	28.6	28.2	22.8	2.1					Rojo-magro, puntos blanquecinos

Table 2: Description and chemical assays (major elements) of 36 soil profiles of the province of Misiones (Taken from Valania,1968). Muestra: Sample. Nivel: level Profundidad: depth, Perdida: lost

Alumina content of Misiones laterites, other than Puerto Peninsula (6 localities), varies between 18.7 and 24.3%. The assay results of some particular samples of these localities are portrayed below:

Apostoles (Angelelli 1984): 41.8% SiO_2, 19.5% Al_2O_3, 15.4% de Fe_2O_3 , 3.7% TiO_2, 0.7 % CaO, 0.4%, MgO, 0.7% NaO_2, 0.2% MnO, 15.2% H_2O,
Caburey (Valania, 1974): 14.4% SiO_2, 27.8% Al_2O_3, 33.8% de Fe_2O_3 , 20.0 % Pérdida a 900ºC
Central Norte 17-A (Valania, 1974): 30.8% SiO_2, 22.5% Al_2O_3, 26.2% de Fe_2O_3 , 15.1 % Pérdida a 900ºC
Central Norte 17-C (Valania, 1974): 6.4% SiO_2, 52.8% Al_2O_3, 11.6% de Fe_2O_3 , 28.7 % Pérdida a 900ºC

2) **Anorthosites:**

There are few known deposits of this rock type in Argentina. The main three are located in the San Juan and La Rioja provinces, in the middle west portion of argentinian territory. There are also some minor occurrences, dikes and lens generated by magmatic segregation processes, in the Calalaste Range of Catamarca Province (Northwesten Argentina).

The biggest deposit is located in the El **Espina**l range, La Rioja Province. It consist in an anorthositic massif outcropping over an área of 29.9 square kilometers (Casquet et al, 2004). The second largest is found 25 kilometers to the southeast of the first. Is also an anorthositic massif and covers a surface of 11.6 square kilometers (Casquet et al, 2004) of the **Maz** range (Figure 3).

Both massifs are part of the Maz Metamorphic Complex (Tholt, 2018 and publications cited there). The complex is integrated by amphibolites, paragneiss and orthogneiss (meta-anorthosites, metajotunites, metamangerites and metagranites). The orthogneiss are interpreted to be the result of a medium to high grade metamorphism of an AMCG complex (**A**northosite, **M**angerite, **C**harnockite, **G**ranite) of grenvillian age (Rapela et al, 2010). Casquet et al. (2005) sugestted, based on geochemical evidences, that the anorthosites origin is related to an anorogenic mantle plume, younger than the Grenville orogenia and starter of the Rodinia breakup. The anorthositic magma source is thought to be a lithophile depleted mantle. The Nd and Sr isotopic composition suggest a contamination of the primary magma by moderated quantities of a lithophile enriched cortical component (Casquet et al. 2005).

The anorthosites and the associated jotunites dikes have been dated in 1070 ± 41 Ma and show evidences of a metamorphic renewing occurred at 431 ± 40 Ma (Casquet et al, 2005). The anorthositic massifs are constituted mainly (95%) by intermediate plagioclase (An_{47-50}) with small and disperse clusters of mafic minerals (amphibol, phlogopite and garnet). The massifs are crossed by ultramafic dikes composed by amphibols, garnets, titanite and apatite. The plagioclases have large to very large grain size (6 to 7 cm long and 3 to 4 cm wide), with some occasional phenochryst of 10x20 cm (Dahlquist, 2008). Chemical assays performed by Dahlquist (2008) show alumina contents oscillating between 24.72 and 27.56% for the Maz range anorthosites (Table 3).

The third anorthosite deposit is part of the La Resina Metamorphic Complex, located in San Juan province, at the southwest end of the Valle Fertil-La Huerta range, in direct contact with the regional fault separating this range from Pie de Palo range (Figure 3, left, and Figure 4). La Resina deposit possess similar characteristics to the previously mentioned deposits, but the available information is much lesser. Most of the data about this massif is found in the work of Boedo et al (2019). They interpret La Resina Complex as an AMCG suite affected by dynamic metamorphism. The complex is conformed by massive anorthositic bodies intruded by granites and ortho amphibolites crossed by mafic dikes. McClelland et al (2005) dated eroded zircons from the complex and obtained ages of 839 ± 10, 1062 ± 20, 1084 ± 4, 1091 ±

15, and 1099 ± 22 Ma. None of this zoned zircons had evidences of grow rings associated to paleozic metamorphism.

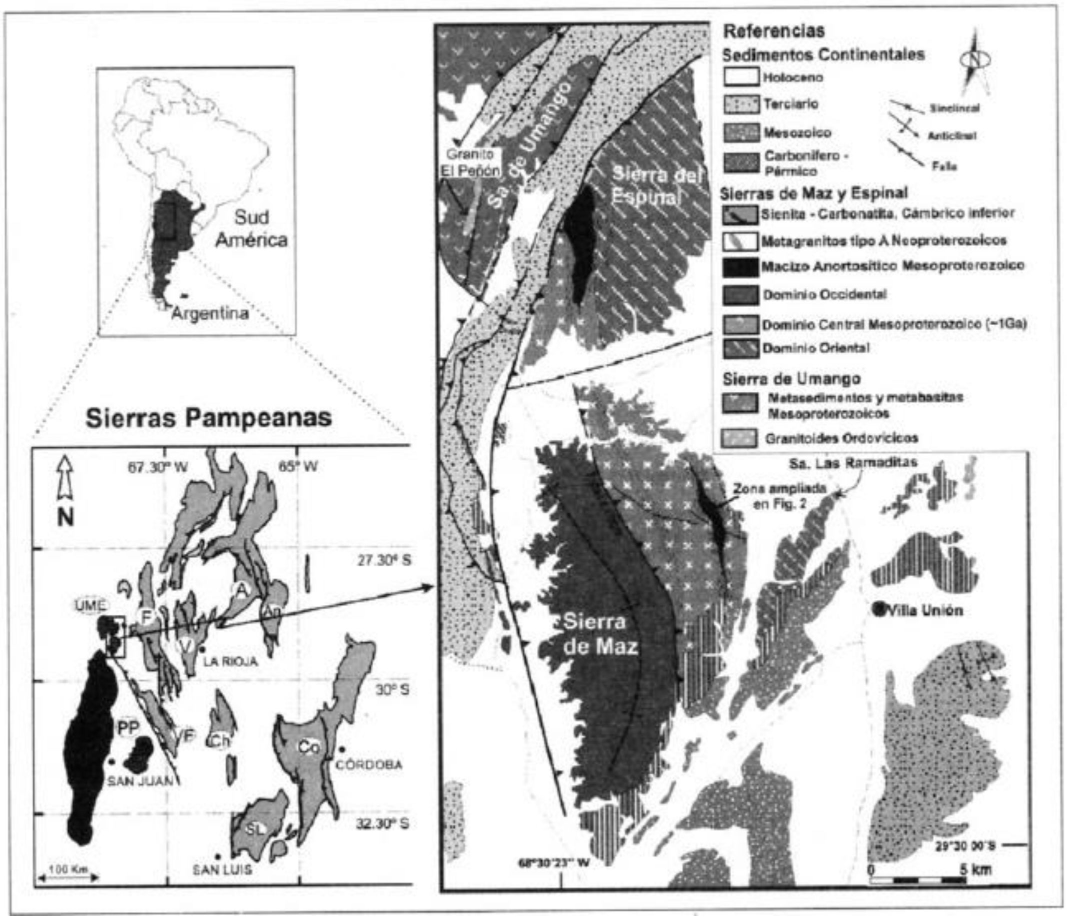

Figure 3: Left: schematic geologic map of the Pampean ranges including Eastern Pampean Ranges (light grey), Western Pampean Ranges (dark gray) and Precordillera (black). Name of the ranges: A: Ambato, An: Ancasti, Ch: Chepes, Co: Córdoba, F: Famatina, PP: Pie de Palo, SL: San Luis, UME: Umango, Maz and Espinal, V: Velazco, VF: Valle Fertil. Right: schematic geologic map of the Umango, Maz and Espinal ranges (Taken from Dahlquist, 2008).

According to Boedo et al. (2019) the anorthosites of La Resina show large to very large grain size with plagioclase crystals of up to 3cm long and amphibol crystals of up to 1cm long. The plagioclase composition (determined under microscope) is between the range of andesine. The alumina content varies between 22 and 26% with potassium values lower than 1% and strontium values of 758 to 920 ppm.

There is no data of the surface extension of the anorthositic bodies, but it is estimated that the La Resina Complex outcrops cover and area greater than 200 square kilometers.

Muestras	Facies a									Facies b		
	MAZ 12053	MAZ 12024	MAZ 7207	MAZ 7215	MAZ 12023	MAZ 7208	MAZ 12052	MAZ 7209	*Prom*	MAZ 12050	MAZ 7211	*Prom*
Mayoritarios (en óxidos y peso %)												
SiO_2	53.12	53.82	53.92	53.99	54.11	54.22	54.61	55.37	54.15	51.17	52.88	52.03
Al_2O_3	26.77	26.36	25.85	27.16	26.15	26.34	27.56	26.68	26.61	23.72	24.28	24.00
Fe_2O_3	1.03	1.07	1.66	0.90	2.09	1.57	0.77	1.08	1.27	6.93	4.45	5.69
MnO	0.02	0.01	0.03	0.01	0.03	0.03	0.01	0.01	0.02	0.13	0.07	0.10
MgO	0.21	0.1	0.22	0.10	0.29	0.16	0.06	0.11	0.16	1.08	0.87	0.98
CaO	9.71	9.09	9.34	10.43	9.57	10.25	10.34	10.01	9.84	9.27	8.75	9.01
Na_2O	4.82	5.3	5.15	5.15	5.27	5.08	5.06	5.19	5.13	4.30	4.92	4.61
K_2O	1.13	0.88	1.49	0.54	0.89	0.42	0.63	0.58	0.82	0.65	1.28	0.97
TiO_2	0.12	0.10	0.18	0.14	0.28	0.19	0.10	0.12	0.15	1.53	1.13	1.33
P_2O_5	0.04	0.08	0.12	0.06	0.09	0.07	0.04	0.05	0.07	0.27	0.37	0.32
LOI	2.09	1.75	1.84	1.37	1.59	0.57	0.91	0.70	1.35	0.77	1.29	1.03
TOTAL	99.06	98.57	99.80	99.85	100.35	98.90	100.09	99.90	99.57	99.82	100.29	100.06
Elementos traza (ppm)												
Cs	0.5	2.6	1.3	0.7	1.5	bld	0.2	0.2	1.0	0.3	0.8	0.5
Rb	18	15	35	7	18	1	5	2	13	7	30	19
Sr	927	838	804	870	812	840	857	806	844	727	816	772
Ba	543	323	297	214	270	163	264	252	291	287	301	294
La	4.32	5.24	7.25	3.84	6.52	6.92	4.25	4.92	5.41	9.93	9.23	9.58
Ce	8.96	9.90	13.62	7.57	12.90	13.65	8.01	8.64	10.41	22.60	20.47	21.53
Pr	1.06	1.06	1.55	0.86	1.44	1.55	0.86	0.91	1.16	2.93	2.63	2.78
Nd	4.04	4.03	6.33	3.58	5.71	6.26	3.11	3.50	4.57	12.60	12.02	12.31
Sm	0.82	0.70	1.16	0.68	1.06	1.16	0.48	0.57	0.83	2.49	2.56	2.53
Eu	1.06	1.68	2.06	1.21	1.74	1.33	1.95	2.22	1.66	2.37	2.25	2.31
Gd	0.71	0.51	1.01	0.58	0.90	1.01	0.40	0.44	0.70	2.42	2.39	2.41
Tb	0.11	0.08	0.15	0.09	0.15	0.14	0.06	0.06	0.10	0.38	0.36	0.37
Dy	0.66	0.39	0.74	0.47	0.82	0.73	0.29	0.30	0.55	2.19	1.85	2.02
Ho	0.13	0.07	0.15	0.10	0.15	0.14	0.05	0.06	0.10	0.43	0.37	0.40
Er	0.36	0.17	0.39	0.25	0.42	0.36	0.14	0.15	0.28	1.23	0.97	1.10
Tm	0.05	bld	0.05	0.04	0.06	0.05	bld	bld	0.05	0.18	0.12	0.15
Yb	0.33	0.11	0.33	0.23	0.39	0.30	0.12	0.12	0.24	1.17	0.77	0.97
Lu	0.05	0.02	0.05	0.03	0.06	0.04	0.02	0.02	0.03	0.18	0.12	0.15
U	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.1
Th	0.4	0.0	0.1	0.2	0.1	0.1	0.2	bld	0.1	0.1	0.1	0.1
Y	3.5	1.8	3.9	2.4	4.2	3.6	1.4	1.5	2.8	11.6	10.1	10.9
Nb	1.4	1.2	8.4	5.3	3.5	5.1	0.8	2.8	3.6	16.4	14.6	15.5
Zr	40	< 4	10	14	6	19	6	5	14	51	34	43
Hf	0.9	0.1	0.3	0.4	0.3	0.4	0.2	0.1	0.3	1.1	0.7	0.9
Ta	0.14	0.02	0.14	0.05	0.15	0.12	0.05	0.04	0.09	1.20	0.56	0.88
Ga	18	22	20	17	21	18	21	21	20	20	18	19
Ge	0.7	0.7	0.8	0.7	0.8	0.8	0.6	0.7	0.7	0.9	0.9	0.9
FeO+MgO	1.1	1.1	1.7	0.9	2.2	1.6	0.8	1.1	1.3	4.9	7.3	6.1
ΣREE	22.7	24.0	34.8	19.5	32.3	33.6	19.7	21.9	26.1	61.1	56.1	58.6
$[La/yb]_N$	8.8	31.9	14.9	11.2	11.2	15.6	23.7	26.9	18.0	5.7	8.0	6.8
Eu/Eu^*	4.3	8.6	5.8	5.9	5.5	3.8	13.7	13.5	7.6	3.0	2.8	2.9

Table 3: Geochemics of the Maz Range anorthosites (taken from Dahlquist, 2008)

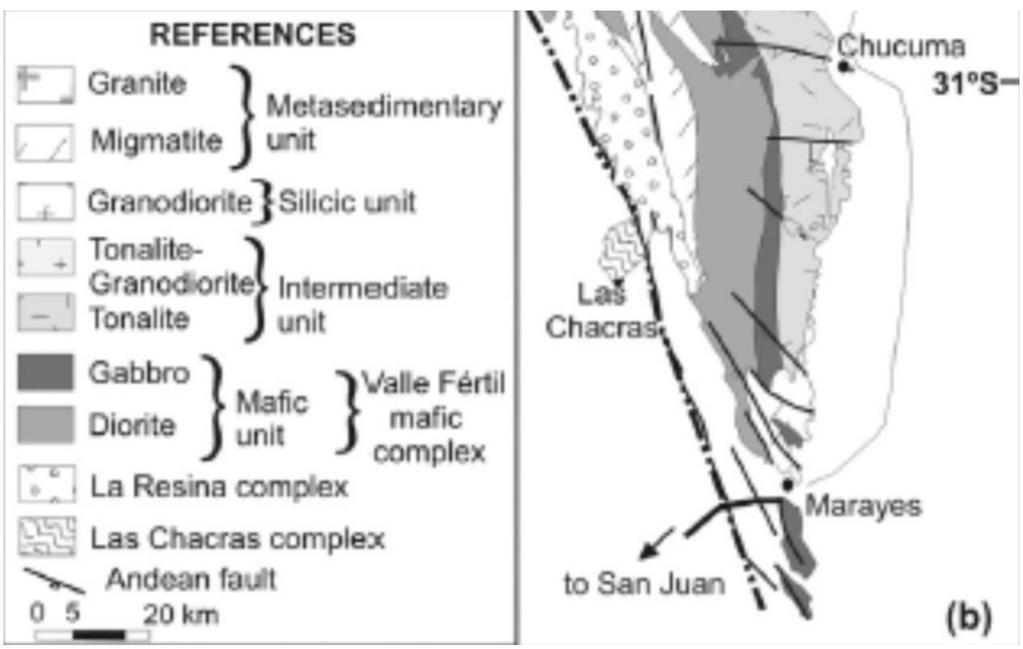

Figure 4: Location of the La Resina Complex in the Valle Fertil-La Huerta range (Taken from Cristofolini et al., 2014).

3) **Kaolin deposits:**

Argentina has numerous kaolin deposits of varied origin. They are mainly developed after the hydrothermal or weathering alteration of feldspar rich volcanites. There are also some sedimentary deposits and others generated by the alteration of plutonites or metamorphic rocks. A large portion of these deposits were exploited since middle 20th century to extract raw materials for the elaboration of ceramics and refractory materials. Table 4 presents the data of the most important deposits found in the bibliography. For the elaboration of this table only deposits with alumina content higher than 20% were selected, excluding the remaining. It is important to have in mind that, due to the antiquity of the information sources, it is possible that the resources registered in the table may have diminished or got exhausted. In addition, it is need to point out that the blank fields in the table are sign of the lack of information in that field for a given deposit.

Province	Deposit	Origin	SiO2 %	Al2O3 %	Tonnage	References
Jujuy	Yuraj	Hydrothermal alteration of Tafna formation tuffs	61.50	21.60	931,250	Reverberi, 1966
	La Lucha		57.90	25.90		
San Juan	La Dehesa (San Juan)	Hydrothermal alteration of volcanites	75.50	20.00		Angelelli et al 1980
	La Dehesa (San José)		75.60	23.49		
Río Negro	La Blanquita	Hydrothermal alteration of rhyolitic tuffs.	50.00	33.04		Hayase et al. 1970
	Sorpresa		65.75	23.34		
	Adelita		68.1-74.44	24.8-17.82		
	Fortuna		67.89	20.46		
	La Chiquita o Las Lagunas		47.01-51.27	32.34-36.07		Terrero y Cannelle, 1948
	Codihué	Hydrothermal alteration of rhyolitic rocks	43.50-45.22	29.05-34.55	50000	Cannelle y Terrero 1949
	Liliana		50.75	33.06		Achear et al, 1999
	General San Martín	Hydrothermal alteration of an ignimbrite	48.75	33.26		
	General Belgrano		45.92	35.90		

	General Juan Manuel de Rosas		47.69	33.63		
	Alfa	kaolinized rhyolite	51.66-60.24	22.37-24.20		
Chubut	Cerro Bayo	Sedimentary ?	43.24-68.36	22.65-41.63	2500000	Sister, 1953
	Blaya Dougnac	Hydrothermal alteration of quartz porphyry	73.56-77.00	16.86-20.72	1500000	Angelelli y Stegmann, 1945
	La Chiquita	Wheathering alteration of tuffs and rhyolites	68.2-70.7	16.7-20.8	740000	Anselmino 1962a
	La Colorada		68.1-73.8	17.0-22.0	110000	Anselmino 1962b
	Colón		45.0-74.7	13.2-25.5	1000	Aspilcueta y Anselmino, 1962
	Villegas y María Magdalena		56.1-77.0	16.1-28.4	25265	Aspilcueta y Anselmino, 1961
	Camarones Terciary	sedimentary	48.78-66.48	19.4-34.1		
	Camarones Quaternary	sedimentary	54.96-71.32	14.53-29.86		Canelle, 1960
	Comallo			32.00-37.00		Angelelli et al 1976, Cuchi, 1998
Santa Cruz	El Ñandú	Hydrothermal alteration of rhyolitic ignimbrites		21.5	1200000	Panza et al, 1994
	El Ranquel			20.60	240000	
	Unión			20.90	280000	

Buenos Aires	Cerro Segundo	Hydrothermal alteration of schists and granites	70.14	20.00-24.00	527312	Angelelli, 1945/ Oliveri, 1954
	María Eugenia	Alteration of dioritic pegmatites	60.02-64.81	21.60-27.15	258346	Angelelli, 1945/ Oliveri y Terrero, 1951
Neuquén	Mina Chita	Sedimentary, redeposited	47.3-57.34	22.48-34.69		Rossi, 1970
La Rioja	Las Mellizas	Sedimentary	28.3-49.9	21.9-36.3	617793	Rossi y González, 1970
	Don Paco		46.4-48.7	19.7-25.2		
	Clarisa		47.1-57.5	24.9-27.5		
	Sonia		45.9	37.88		
	San Antonio		38.6-45.0	19.2-33.0		
	Mogotes Colorados		36.7-45.3	19.6.-20.1		
	La Prudencia		63.2	20.5		
	Don Alberto		60.5	23.4		
	Libertad		53.5-60.2	20.3-23.4		
	El Dorado		57.8	21.3		

Table 4: Summary of the alumina and silica contents, and estimated tonnage of the main kaolin deposits of Argentina

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4) **Cerro Negro Cordieritite:**

This formation, outcropping at the northwestern of Cordoba province, was considered by Candiani et al (2001) as part of the Pichanas Metamorphic Complex (Lyons et al., 1997) and the associated S-Type granites. Rapela et al (2002) included the cordieritite bodies within the El Pilon Granitic Complex and considered that its origin was due to the chrystalization of magmatic cordierite, generated by the combination of a peraluminous granitic magma with fluids derivated from the partial melting of the hydrous and aluminum-rich wall rock. The formation process of the cordierite rich rocks would have occurred under high temperature and low pressure conditions, in the top side of a laccolith.

The resulting rocks form ovoid bodies of 150 meters long and 10 meters wide, constituted by 70% to 80% cordierite with biotite (5%-·35%), quartz (5%-10%), sillimanite (3% – 10%) and plagioclase (1% – 5%). The cordieritites are found in two varieties, a massive one, of large grain size, and the orbicular, wich contains ovoid orbicules of up to 20cm long with cordierite rich rims and biotite and sillimanite rich cores (Candiani et al, 2001). The average alumina content of the cordieritites is about 30% with silica contents of 49% (Gordillo, 1974).

5) **Alunite:**

In the proximity of Camarones town, Chubut province, over an area of about 15 kilometers around downtown, a bentonitic clay horizon outcrops. It conforms the upper part of the Río Chico Formation (Lema et al, 2001 and works cited there). Within this horizon irregular and angulate nodules of silicified alunite are found. The size of the nodules varies between 10 to 150 cm, being the average size 30x40x50 cm (Anselmino, 1967).

The nodule distribution is not homogeneous along the bentonitic horizon and 18 mineralized bodies have been identified (Sister y Klein 1952). Four of them, where the nodules cover up to 80% of the clayous strata area, were explored and measured (Anselmino, 1967). The result of this studies, carried on through the drilling of 108 explorative holes, was the estimation of 593432 tonnes of resources with alumina grades of between 24% to 32% .

The nodules`s alunite is constituted by a 70% of potassic alunite and a 29% of natroalunite. It is attached with kaolin and cristobalite (Hayase et al., 1971). To the microscope, silica is observed forming the walls of cells constituted by alunite chrystals (Sister and Klein, 1952).

The genesis of the nodules has not been stablished with certainty. Both, Anselmino (1967) and Camaco (1971) hypothesized an origin related with acid meteoric water circulation through the cracks of the bentonitic horizon, producing clay leaching and the precipitation of silica and alunite. The bentonitic horizon, for his part, would have been originated by the weathering alteration of the Eocene rhyolitic tuffs of the Rio Chico Formation. Camacho postulated that the bentonite formation would have been produced in an alkaline environment and that a weather change or a shifting in the surficial waters sources areas would have acidified them, leading to the formation of alunite and colloidal silica. He also estimates that the nodules formation took place in an environment of hot weather with high evaporation.

4. Mining production

Argentina does not have aluminum mining production, nor historic nor ongoing.

5. Concluding Remarks

Although its lack of bauxite deposits Argentina possesses a variety of possible aluminum sources with alumina grades greater than 20%. All of them need of the uprising of new metallurgical technologies to be consider as possible economical sources of aluminum. Meanwhile it is recommended to update the information regarding them, since most of it comes from works of more than 40 years old. It is also recommended for SEGEMAR to have in mind, at the moment of generate new base information for the country (geological or metallogenical), to conduct routinary assays in peraluminous rocks with possibility to be non-traditional aluminum sources (clays, granites, sienites, pegmatites, metamorphic rocks derived from this rocks, etc.). The implementation of these recommendations will allow the country to have an updated and reliable database for aluminum deposits, maybe extending the list of them reported here, when the new metallurgical technologies finally arrive.

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