PRODUCTION OF ALKALI FELSPAR AND NEPHELINE AT THE CERRO SIETE CABEZAS COMPLEX (ALTO PARAGUAY): A PILOT STUDY

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ABSTRACT

A pilot study, relative to the feldspars-nepheline eco-sustainable exploitation, was planned in an economically depressed area from the Paraguyan Chaco, i.e. Alto Paraguay river, Cerro Siete Cabezas complex. The latter represents an alkaline complex made of prevailing syenitic rocks. A twenty years business plan may allow to a whole profit of about 304 U$ million dollars, and a final conversion to a touristic locality similar to that existing in the near brazilian side of the Paraguay river, i.e. Porto Murtinho town. Analogous industrial models may be applied to the many similar alkaline complexes in the South America platform.

***Keywords**: Alkali feldspar, nepheline, exploitation, industrial plan, environmental restore.*

INTRODUCTION

Alkali feldspars and nepheline are of major importance in the glass and ceramic industries because of their high Al, Na and K contents. These elements act as a flux that affects the rate and temperature of melting, the fluidity of the melt, and the physical properties of the finish products [1]. Small amounts are also used in paints and as filler in plastics. The major deposits are related to the syenitic hypersolvus complexes, pegmatites and feldspatic sandstones. Whatever the source, alkali feldspars and nepheline (undersaturated variants) must be separated from the associated minerals, generally quartz (oversaturated variants) and mafic minerals.

In this paper a pilot study is presented relative to the exploitation of a syenitic complex from the Alto Paraguay river [2], i.e. Cerro Siete Cabeza body (Paraguayan Chaco), for:

1. the geological and petrographical characteristics;
2. the geographic location, for which the Paraguay river allows to satisfy the water requirements in the exploitation and concentration processes, other than to represent the more suitable and economic transport way;
3. the presence of a suitable electrical energy net;
4. the possibility to place in situ, i.e. along the river, both the concentration plants and a fluvial harbour (Fig. 1);
5. the economic potential;
6. aptitude to the environmental restore.

GEOLOGICAL BACKGROUND

Paraguay, located at the westernmost side of the Paraná-Angola-Etendeka system, represents a peculiar magmatic province in and around the Paraná basin because six main magmatic events have occurred in a relatively restricted area (i.e. less than 120,000 km^2) from the end of the Paleozoic to the Cenozoic, as shown by geological evidences and by previous regional and geochronological studies [2, 3].

The magmatic events can be summarized as (Fig.1):

1) Triassic sodic magmatism of the Alto Paraguay Province (241.1 ± 1.2 Ma; [4, 5] widespread at the southernmost side of the Amazon Craton [2, 3].

2) Potassic alkaline-carbonatitic complexes and dykes from North Eastern Paraguay, from the Rio Apa (~142 Ma; [6]) and Amambay areas (avg. 141 Ma; [7, 8]) which predates the tholeiitic flood basalts (Paraná, Serra Geral Formation, SGF). Recent 40Ar/39Ar age data give 138.8 ± 0.7 Ma both for Rio Apa and Amambay volcanic rock-types [4].

3) The Paraná SGF flood tholeiites and dykes, both represented by high-Ti and low-Ti variants, have ages 134 to 130 Ma, according to [4].

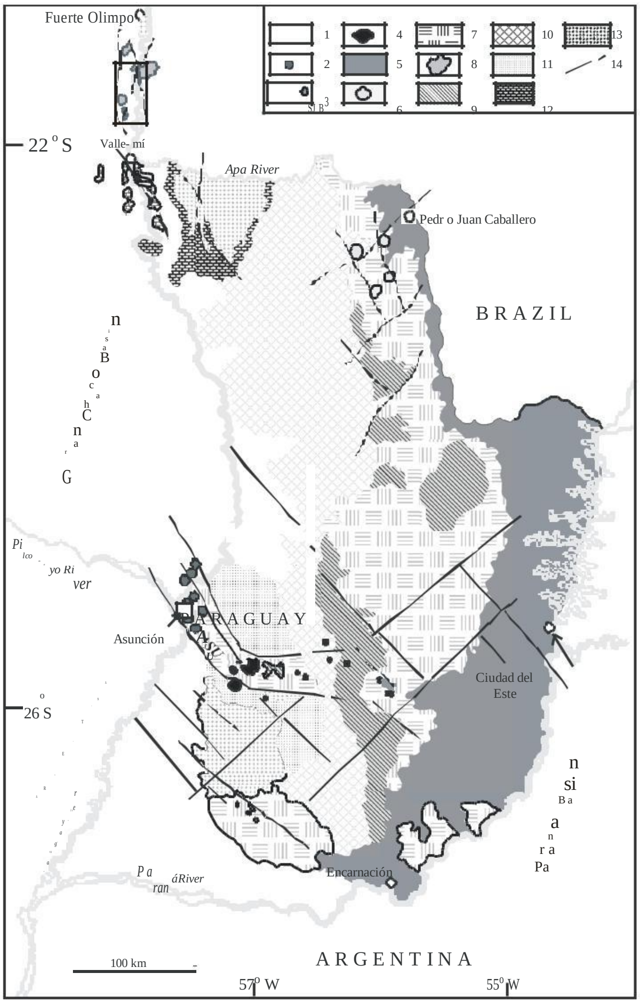

Fig. 1 . Geological map of the Eastern Paraguay (after [2, 3]). 1: Neogene and Paleogene sedimentary cover (Gran Chaco; Argentina, partim; Eastern paraguay); 2: Paleogene sodic alkaline rocks; 3: late Lower Cretaceous sodic alkaline rocks (Misiones province, San Juan Bautista, SJB); 4: Lower Cretaceous potassic alkaline rocks (post-tholeiites); 5: Lower Cretaceous tholeiites of the Paraná basin; 6: Lower Cretaceous potassic alkaline rocks (pre-tholeiites); 7: Jurassic-Cretaceous sedimentary rocks (Misiones Formation); 8: Triassic alkaline rocks (Alto Paraguay province); 9: Permian sedimentary rocks (Independencia Group); 10: Permo-Carboniferous sedimentary rocks (Coronel Oviedo Group); 11: Ordovician-Silurian sedimentary rocks (Caacupé and Itacurubí Groups); 12: Cambro-Ordovician platform carbonates (Itacupumí Group); 13: Archean and Neo-Proterozoic crystalline basement: high- to low-grade metasedimentary rocks, metarhyolites and granitic intrusions; 14: faults.

4) Potassic alkaline complexes and dykes (126.8 ± 1.3 Ma; [4, 5] with subordinate silico-carbonatite flows and dykes, are widespread mainly in the Asunción-Sapucai-Villarrica graben (ASU, central potassic province; [5, 9].

5) Sodic alkaline complexes, plugs and dykes (118.3 ± 0.9 Ma; [10, 11]), occurring mainly at the Misiones Province (San Juan Bautista Region), southwestern Paraguay.

6) Paleogene sodic alkaline complexes, plugs and dykes (58.4 ± 2.1 Ma; [3, 9, 10]) cropping out at the western side of the Asunción-Sapucai-Villarrica graben.

In particular, the Triassic rocks form subcircular complexes following a N-S trend at the border between the Chaco and Pantanal neo-basins, and are mainly formed by nepheline syenites and syenites and their effusive equivalents [2]. In this context, Cerro Siete Cabezas represents the southermost outcrop of this Permo-Triassic magmatism [12].

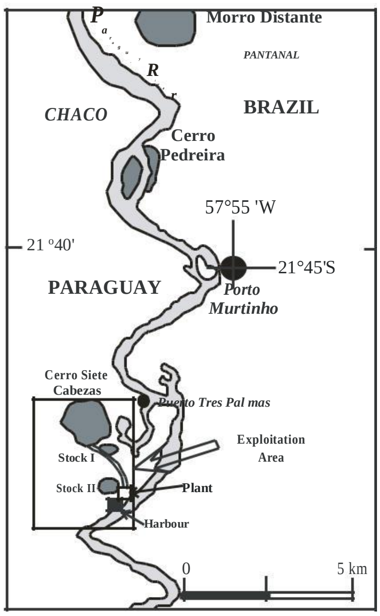

Fig. 2. Sketch map showing the Cerro Siete Cabezas complex in the Alto Paraguay river and the possible location of a plant and of a fluvial harbour. The building access road indicates the connection between the plant-harbour and the alkaline main complex.

GENERAL OUTLINES OF THE CERRO SIETE CABEZAS

Cerro Siete Cabezas constitutes a circular complex (Fig. 2, 3) associated with two minor bodies (Stock I and Stock II of Fig. 2). The circular intrusion covers an area of approximately 4 km^2 and it is characterized by undersaturated medium- to coarse-grained syenitic rocks. Stock I forms an elongated body (1.0 x 0.2 km), 138 m high, with prevailing quartz-bearing rocks. Stock II is a circular body of about 0.4 km^2, 120 m high, and formed by coarse-grained syenitic quartz- or nepheline-bearing, rock-types. All the rocks are of hypersolvus type.

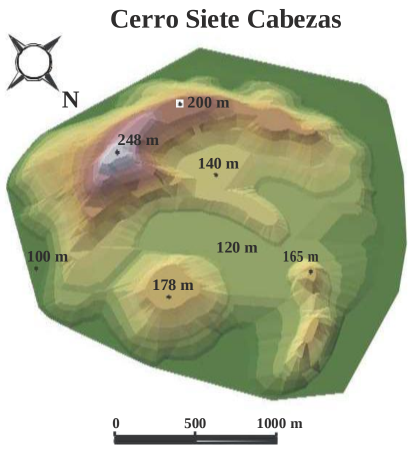

Fig. 3. 3-D representation of the Cerro Siete Cabezas complex.

Averaged modal analyses are represented in Table 1 and averaged chemical compositions of alkali feldspar and nepheline are shown in Table 2. To be noted that the main mafic mineral is amphibole, which is found associated with a green clinopyroxene and biotite in variable amounts and sometimes forming clusters and/or complex intergrowths. Opaques (magnetite and ilmenite) are ubiquitous. Many rock-types have as accessories apatite, titanite, zircon and fluorite. Zr-rich eudyalite, rosembuschite and låvenite are rare, but common phases in the Cerro Siete Cabezas complex. In particular, the latter and zircon may be considered as subproducts of the exploitation and of the economic plan for zirconium (not here considered).

EXPLOITATION PLAN

The whole ore potential was extimated around 130,000,000 cubic meters, but in the time plan only 30 million cubic meters will be mined over an area of about 2.0 km^2, mining about 1500,000 cubic meters/year for twenty years.

The mining area was subdivided in four main lots, each following a period of five years (Fig. 4). The mining fronts, performed by explosives, are represented in Fig. 5. The tridimensional model, calculated at the mining end, is shown in Fig. 5.

Table 1. Averaged modal analyses of the main rock-types from Cerro Siete Cabezas complex; in parenthesis the standard deviation. Mafic minerals include the accessories (A); Zr(B): vol% of zircon + other Zr bearing minerals (s. text).

Vol%	Cerro Siete Cabezas n = 25	Stock I n = 10	StockII (A) n = 10	Stock II (B) n = 3
Quartz		6.6 (6.0)	1.5 (1.2)	
Alkali feldspar	69.8 (9.6)	84.4 (8.7)	88.8 (2.9)	63.0 (2.8)
Nepheline	10.7 (4.3)			19.1 (1.9)
Mafic minerals(A)	19.5 (5.5)	9.0 (2.5)	9.7 (3.4)	9.9 (2.5)
Zr(B)	0.33 (0.25)	0.40 (0.10)	0.34 (0.09)	0.30 (0.10)
(B)/(A) ·100	1.7 (1.2)	4.4 (1.1)	3.5 (0.9)	1.5 (0.5)

Table 2. Averaged chemical analyses of alkali feldspar and nepheline from Cerro Siete Cabezas complex.

	Alkali Feldspar					
	Cerro Siete Cabezas		Stock I		Stock II	
wt%						
SiO_2	67.02	(0.25)	66.75	(0.60)	67.18	(0.91)
Al_2O_3	19.14	(0.27)	18.74	(0.29)	18.82	(0.33)
Fe_2O_3	0.19	(0.15)	0.23	(0.04)	0.31	(0.23)
CaO	0.16	(0.02)	0.05	(0.04)	0.12	(0.08)
Na_2O	7.49	(0.34)	7.24	(0.33)	7.20	(0.40)
K_2O	6.04	(0.48)	6.47	(0.41)	6.50	(0.61)
Sum	100.04		99.48		100.13	
Mol%						
Or	34.2	(2.8)	36.9	(2.5)	36.8	(3.5)
Ab	64.5	(2.8)	62.6	(2.6)	62.1	(3.2)
An	1.3	(0.4)	0.5	(0.4)	1.1	(0.7)

Table 2. Cont.

	Nepheline Cerro Siete Cabezas	Stock I
wt%		
SiO_2	44.22 (0.48)	42.78 (0.07)
Al_2O_3	33.32 (0.59)	33.77 (0.52)
Fe_2O_3	0.62 (0.21)	0.35 (0.30)
CaO	0.04 (0.02)	0.30 (0.20)
Na_2O	16.33 (0.26)	16.22 (0.16)
K_2O	5.62 (0.02)	6.61 (0.56)
Sum	100.15	100.03
Mol%		
Q	5.4 (0.8)	2.4 (0.5)
Ne	75.6 (0.7)	75.2 (0.8)
Ks	19.0 (0.3)	22.4 (1.3)

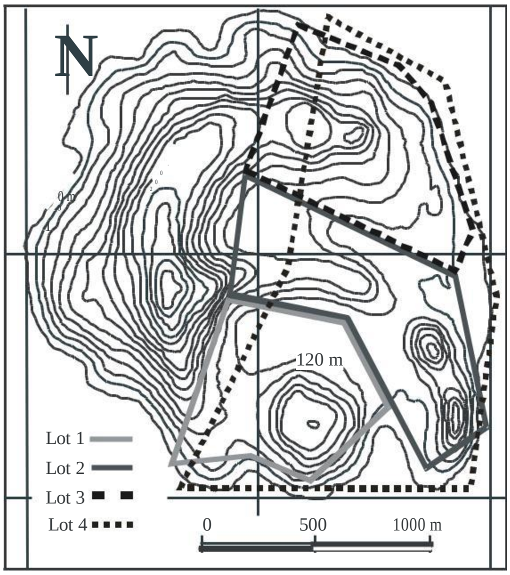

Fig. 4. Graphic representation of the four exploiting lots in the Cerro Siete Cabezas complex.

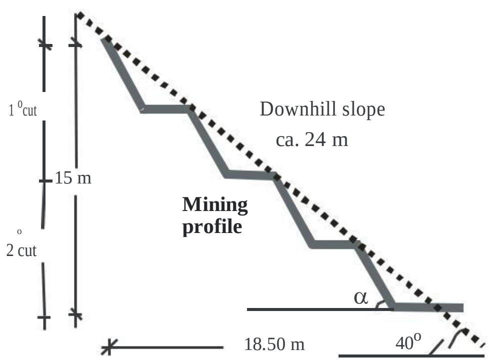

Fig. 5. Representative section of excavation front during the exploitation.

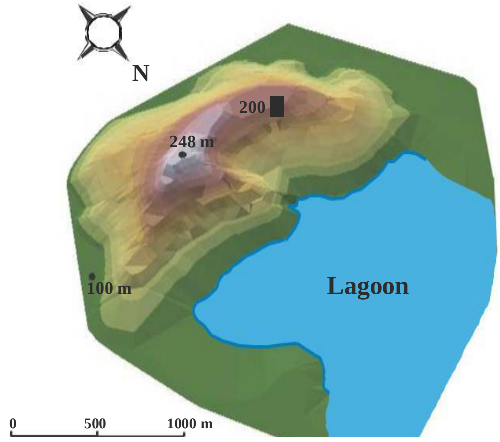

Fig. 6. 3-D representation of the Cerro Siete Cabezas complex at the end of the mining.

SEPARATION TECHNIQUES

Flotation [13] is an efficient, but expensive technique for feldspars+nepheline - quartz separation, where the feldspars + foids are floated, while quartz is depressed. Moreover, fine particle size are required and the use of chemical additives and reagents significatively increase the operating costs of the process and cause environmental pollution for the toxicity of the chemical products.

In comparison, electrostatic separation [14, 15] requires a minor degree of comminution of the feed materials, but operates under dry conditions. Dry comminution produces significant quantities of fine particles that must be removed (e.g. air scrubbing processes). In general, these separators have low unit capacity and normally require that the surface of the particles are conditioned by HF vapours or by heating.

Although these techniques produce alkali feldspar (and nepheline, undersaturated variants) and quartz (oversaturated variant) products in very high concentration (i.e. > 99%), however the ceramic industry generally uses felspathic raw materials mixtured with quartz. It follows that less selective, but more economic and environmental friendly alternative techniques can be utilized.

Under this aspect, dynamic dense media separators, like Tri- Flo, represent an intersting alternative [16, 17, 18], and it is suggested as the more suitable plant for the Cerro Siete Cabezas area. In the Tri-Flo, an appropriate medium density is produced by ferrosilicon and/or magnetite, which are inert materials, and toxic or hazardous additives are not required. Moreover, a grain-size coarser than that required by flotation or electrostatic techniques, is used, enabling a reduction in the feed mineral comminution.

The Tri-Flo separator

The separator consists of two or more cylindrical chambers connected in series, such that the float material of the first chamber feeds the second chamber, and is reprocessed.

Each chamber may operate with a different medium density, but, for a single density separation, the same medium density is feed to the two stages of the vessel (Fig. 7). The plant is described in detail in Zanetti [19].

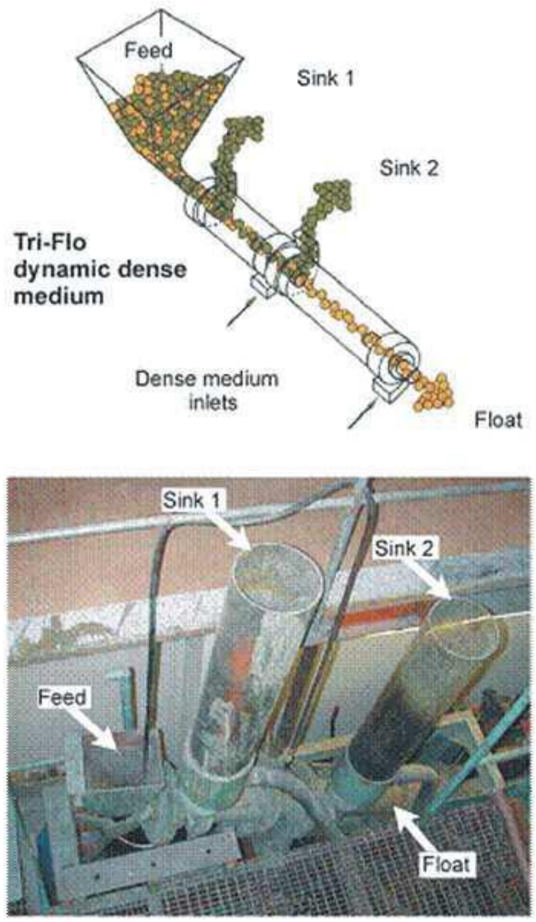

Fig. 7. Scketch relative to the "Tri-Flo" cylindric separator (one density model).

BUSINESS PLAN

The whole project, mining, plant and harbour construction, makes provision for a twenty years business plan, with a whole production of 42,000,000 tons and a profit of about 304 US$ millions (Table 3; Fig. 7), inclusive of the environmental final adaptements to a touristic area (cf. Fig. 6). The latter could be organized for hunting and fishing, similar to that actually existing in the Porto Murtinho town, on the Brazilian side of the Paraguay river.

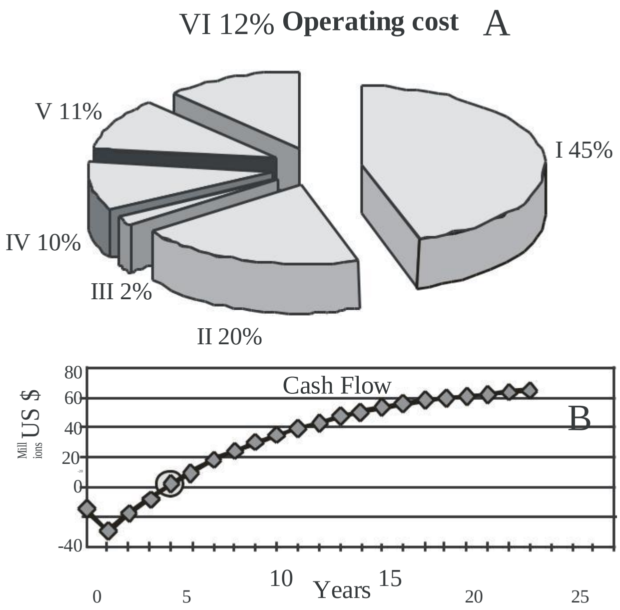

Fig. 8. Business plan. **A**: operative costs (I, treatment of the materials; II, load and moving; III, environmental restore; IV, mining; V, general gestional costs; VI, ore services). **B**: actualized cash flow.

Table 3. Major economic parameters for the businness plan (US $).

Investment year 0 [Millions $]	15
Investment year 1 [Millions $]	15
Revenues/Year [Millions $]	50.7
Operating costs [Millions $]	35.5
Profit/Year [Millions $]	15.2
Internal Rate of Return [%]	37
Discount rate (constant) [%]	13
Net Present Value [Millions $]	64.5
Pay Back Period [Years]	3.8

CONCLUDING REMARKS

A possible industrial application, 20 years plan, relative to the alkaline complexes, Alto Paraguay river, is envisaged in an economical depressed area, i.e. Paraguaian Chaco. A projection of a possible conversion on the touristic business is suggested after an eco-compatible exploitation plan, with the aim of encouragement in ecosupporting the economic development of the region.

Obviously, this approach may be extended to all the favourable occurrences in the southamerican platform, e.g. at the alkaline complexes from Bolivian Velasco Province.

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