REPORT URUGUAY- DINAMIGE

ANORTHOSITES OCCURRENCE

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Content

ANORTHOSITES OCCURRENCE IN URUGUAY

1. INTRODUCTION

An international level, anorthosites are being investigated for several industrial uses mainly as an alternative of raw materials for the aluminum industry (Wanvik, 2000), featuring a wide variety of industrial applications (Table 1). Mineral exploitation of anorthosites for industrial products is growing and the potential for future production of aluminum and other important constituents is being considered.

Processing	Products	Uses	Specifics
Physical.	Plagioclase grains with crystal structure intact	Aggregates	*Light coloured road surfaces, gardens,*
(dry or wet mineral		Building materials	*Concrete elements, dimension stone, industrial floors*
processing)		Abrasives	*Scouring powder, toothpaste,* sand blasting
		Fillers, extenders, coatings	Paint, plastics, rubber
Chemical	Aluminium chlorides	*Aluminium metal*	
	Aluminium oxide (alumina)	*Flocculent*	*Water and waste water treatment*
(acid or alkaline	Aluminium sulphate (alum)	Flocculent/sizing	Paper manufacture
leaching)	Calcium carbonate	Binder	Asphalt
	Calcium nitrate	Catalyst	Organic reactions
	Calcium silicate		Alumina speciality products
	Ammonium nitrate		Cellulose insulation
	Silica gels and sols		Cement components
	Sodium silicates		Cosmetics and pharmaceuticals
	Sodium carbonate		Food processing
			Nitrogen fertiliser
			Speciality metallurgical uses
			Synthetic wollastonite and zeolite
	Silica residue	Fillers and extenders	Polyester and epoxy resins, Poly-urethane varnishes
		Coating	White enamel
		Absorbent	Kitty litter, radioactive pactides
		Silicon production	
			Cement additive
Melting	Fully or partial melting of plagioclase grains	Ceramics	*Floor and wall tiles, electrical porcelain, bioceramics, ceramic glazes*
		Glass fibre	
		Mineral Wool	*Rockwool*
		Welding fluxes	
		Al-production cells	*Cryolite bath insulation*
Direct reduction	*Al-S -alloys, Al- and Si- metal.*		

Table 1: Industrial uses of anorthosites (taken from Wanvik, 2000).

Within the framework of the AlSiCal Project, the search for information regarding occurrences of anorthosites in Uruguay is carried out. The Metallogeny and Mineral Resources Group of the Association of Iberoamerican Geological and Mining Surveys (ASGMI) is committed to meeting the objectives of the AlSiCal Project, with the purpose of providing a report by country regarding occurrences of anorthosites or on the aluminum industry of those producing countries.

At present in Uruguay an occurrence of anorthosites is known, this is located to the North-Northeast of Colonia Department (SW of Uruguay) in an area known as *Cerros Negros*, near Mal Abrigo town (Figure 1).

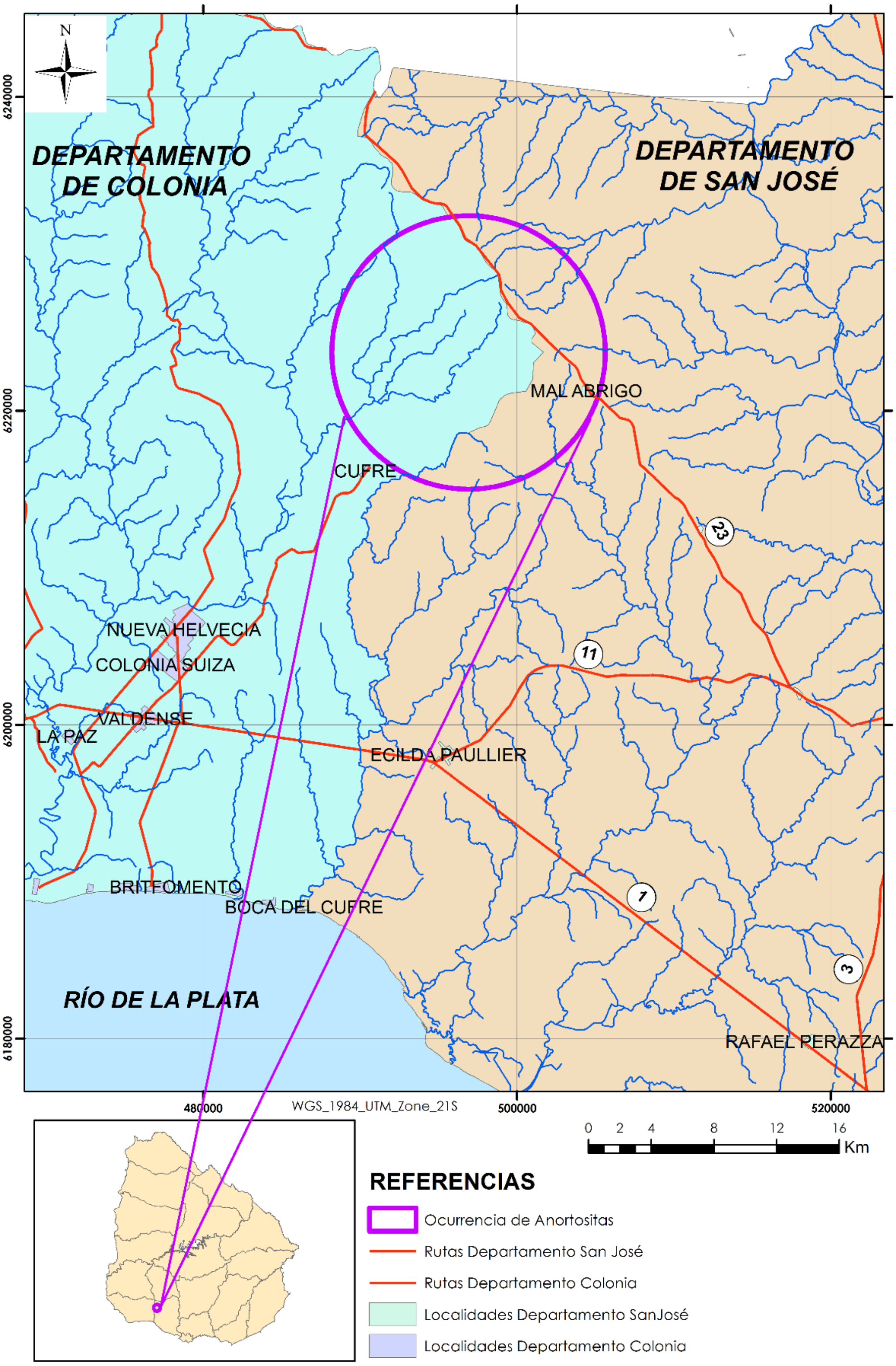

Figure 1: Anorthosites occurrence in Colonia Department, SW of Uruguay.

2. GEOLOGICAL REVIEW

In their geological mapping, Curbelo et al. (2019) recognize that near Mal Abrigo town an interesting geological unit has been identified by different authors, such as Arrighetti & Fay (1981), Coronel et al. (1990) and Spoturno et al. (2004). These authors has presented various names for this unit such as “*Set associated with deep metamorphites*” (Arrighetti & Fay, 1981), *“Cerros Negros Anorthositic Leucogabbro”*, “*Cerros Negros stratified mafic-ultramafic Complex*”, “*Cerros Negros banded leucogabbro*” (Coronel et al., 1990), “*Cerros Negros Metagabbros*” (Spoturno et al. 2004), among others.

The first geological research in this area consisted in a preliminary geological mapping, where those rocks were recognized and mapped as early as 1981 by Arrighetti & Fay as anorthosites. It should be noted, that on the 1st Uruguayan Congress of Geology held in March 1990, a field trip was made to the area, where Dr. Page stated that those rocks, denominated as “*Cerros Negros leucograbbro*” in generic form, would be comparable to a layered intrusion Bushveld Igneous Complex-type. The reconnaissance made in Coronel’s work, show that those rocks vary from anorthosites to ultramafic rocks (pyroxenites) with abundant and sometimes predominant intermediate terms (gabbros, leucogabbros, and metagabbros). The texture would be cumulate (Coronel et al., 1990).

3. GEOLOGICAL SETTING

The Piedra Alta Terrane (PAT) it is the western part of Paleoproterozoic basement and represent the Rio de la Plata Craton (RPC) in Uruguay. PAT is composed of vast granitic gneiss areas separated by supracrustal metamorphic belts of volcano-sedimentary origin. Two main belts have been recognized: the San José Belt (Bossi et al. 1993; Oyhantçabal et al. 2003, 2007; Sánchez Bettucci et al. 2010) located in southernmost Uruguay and the Arroyo Grande Belt (Bossi and Ferrando 2001), which crops out in the northern part of the terrane. The Florida central granitic gneiss belt make up the bulk of the central area located between Arroyo Grande and San José Belts (Figure 2).

The Florida dolerite dike swarm, which is more than 100 km in width, trends c. 060° and extends for more than 300 km along the terrane, cuts the PAT corresponding to extensional event during the Statherian (Halls et al. 2011).

The San José Belt is volcano-sedimentary succession constituted by the Paso Severino, San José, and Montevideo Formations; is considered as belonging to a single belt interrupted by the development of a rift (Oyhantçabal et al. 2011). However, other authors separate the Pando belt to the south due to the existence of the Colonia Shear Zone (Bossi et al. 2005), a thick shear band composed of two mylonitic stripes with sinistral movement (Gianotti 2009).

The Paso Severino Formation occurs to the north of the Cufré Shear Zone and is a greenschist facies folded volcano- sedimentary succession. The formation is divided into NE- and NW-trending sectors; due to the influence of conjugate NNW dextral and ENE sinistral shear zones (Oyhantçabal et al. 2003).

The Cerros Negros complex, intruding the San José belt, is represented by pyroxenite, gabbro, leucogabbro and anorthosite. It displays a conspicuous banding and is affected by deformation and low-grade metamorphism. In addition, it is cut in the southern part by the Cufré shear zone, and to the north and west is intruded by granitic intrusions (Oyhantçabal et al. 2007).

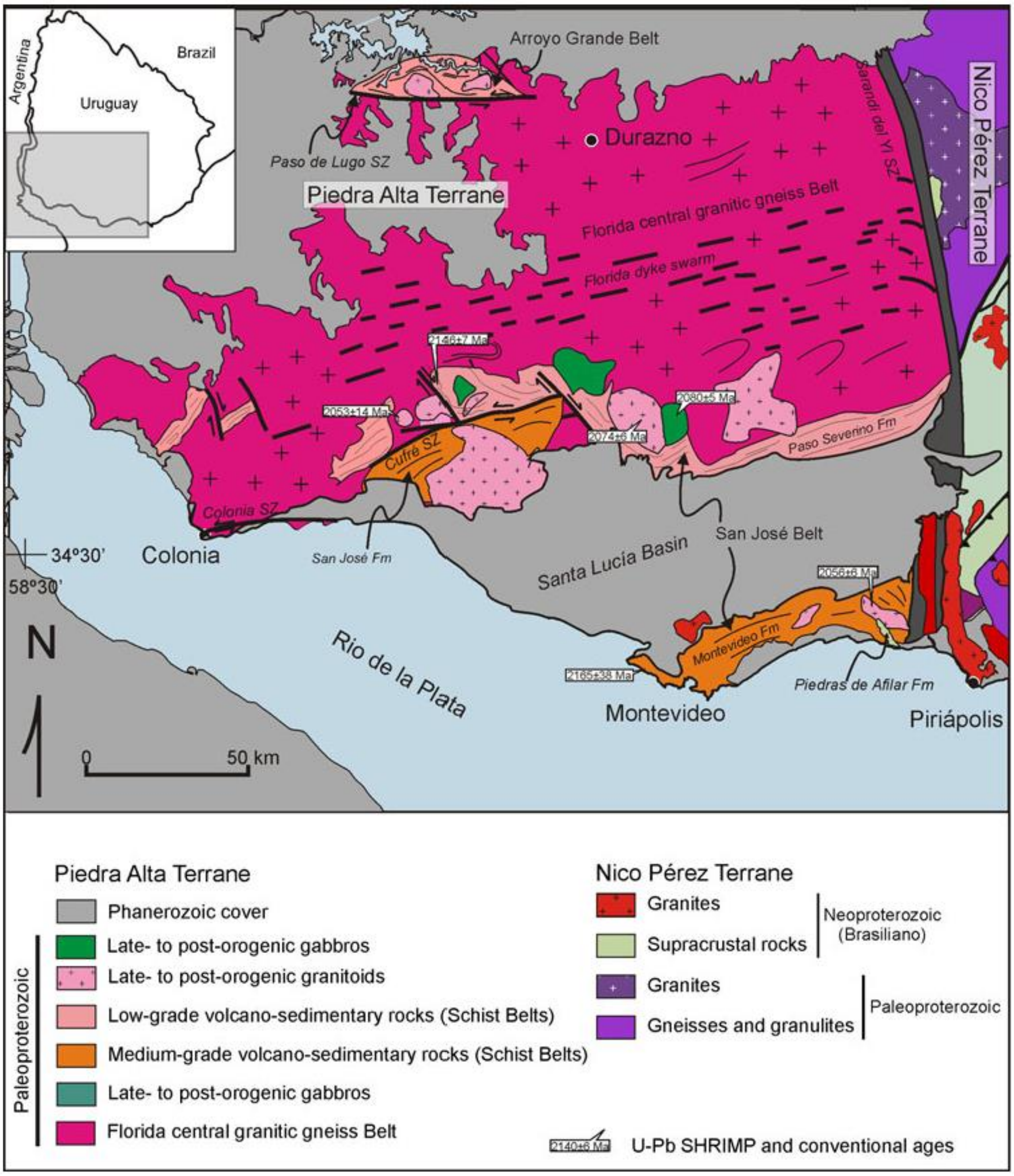

Figure 2: Geological map of Piedra Alta Terrane, Uruguay (taken from Oyhantçabal *et al.*2011)

Geological overview

The geology surrounding Cerros Negros is made up of the following units, identified by Curbelo et al. (2019), as shown in Figure 3: Leucocratic orthogneiss with biotite and amphibole, Paso Severino Formation, Mal Abrigo Granite and mylonitic rocks associated with the Cufré Shear Zone (CSZ).

3.1 Leucocratic orthogneiss with biotite and amphibole

It develops to the west of the Cerros Negros complex, which consists of medium to coarse-grained orthogneiss, with a granoblastic to lepidonematoblastic texture, developing a spaced and irregular anastomosed foliation, given by mafic minerals. The occurrence of smoky black quartz veins and pegmatites and aplites dykes of variable size that follow the structural trend of the area is common. The mineral association is given by quartz, alkali feldspar, plagioclase, biotite, hornblende, titanite and epidote. Contains apatite and opaque minerals as accessories. Biotite and hornblende with greenish-brown color are associated.

Towards the eastern edge of the unit, close to the Cerros Negros mafic complex, there is a series of granitoids rich in feldspar and greyish quartz.

3.2 Paso Severino Formation

It develops east of Cerros Negros complex, it consists of a volcano-sedimentary sequence in which three types of zones can be distinguished, where (i) metasedimentary, (ii) acidic metavolcanic and (iii) basic metavolcanic. Of these three types, the predominant lithology in the area is the metavolcanic (Spoturno et al., 2004).

It outcrops to the Northeast of Curbelo's study area and consist in low-grade metamorphosed volcano-sedimentary basement of the intrusive tectonic syn-tardi bodies of Mahoma Gabbro and Mahoma Granite (Spoturno et al., 2004). Arrighetti & Fay (1981) illustrate in a N-S cross-section the lithology present: *"green rock, acidic metavolcanic and tuffs, quartzite, sericite schist, black schists and limestones."*

3.3 Mal Abrigo Granite

Arrighetti & Fay (1981) and Preciozzi et al. (1985) described this unit as a granite massif consisting of a prominent landform, in contrast to basic rocks of Cerros Negros complex located immediately to the South. It is pink granite with an equigranular, phaneritic texture. Composed by subhedral crystals, larger than 0.5 cm, of feldspar, quartz and biotite. The Guaycurú Shear Zone affects, at it is eastern edge, the granite (Spoturno et al., 2004).

3.4 Cufré Shear Zone and associated mylonites

These lithologies have scarce outcrops, being generally covered by soil and / or colluvium. The outcrops are flat, forming small patches or isolated weathered wedges.

The Cufré Shear Zone forms SWW-NEE strip to the south of Curbelo's study area, generating a transcurrent fault to the south of Cerros Negros complex.

It has been named and described as the "Pueblo González fault" (Preciozzi et al., 1985), the "Cufré-Mal Abrigo mylonitic belt" by Coronel et al., (1990) or the "Cufré-Puntas de Cañada Tabárez Shear Zone" by Spoturno et al. (2004).

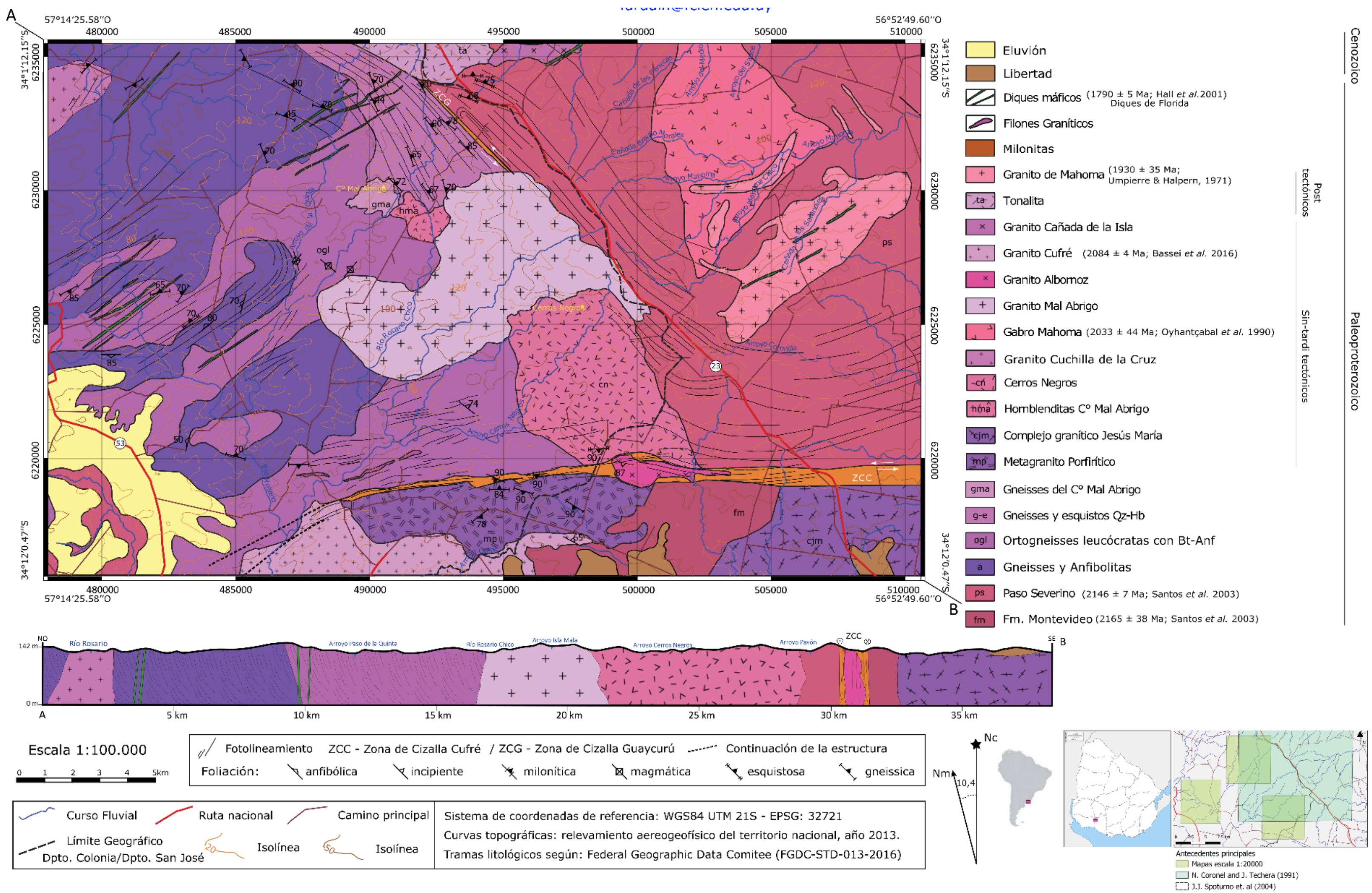

Figure 3: Geolocial maping of the Mal Abrigo topographic sheet, taken from Curbelo *et al*. 2019. See the geological unit of interest: “Cerros Negros-cn”.

4. CERROS NEGROS GEOLOGY

Cerros Negros complex is characterized by generating low-density outcrops in low hillslopes and significant densities in high parts, with a good state of preservation (Figures 4A, B). Consists of mafic rocks where textural variations are observed depending on the grain size (Figure 4C). In addition, variations in the abundance of olivine and pyroxene are distinguished.

Mineralogy

The mineralogical composition of this unit is characterized by plagioclase, clinopyroxene (augite), olivine and orthopyroxene (Figure 4D). The relative abundance of these minerals is variable, observing cases in which plagioclase represent almost 90% of the sample in thin section, thus the rock being classified as anorthosite, and cases where they represent between 50-60%, being classified within the gabbroic domain. In a hand specimen, it is possible to observe tabular subhedral plagioclase, less than a centimeter long and 0.5 cm wide, although there are grains with larger dimensions. In the sub-aphanitic textures, it is also possible to distinguish a set of oriented plagioclase with dimensions smaller than 1.5x0.3 cm, with a characteristi cluster and development of polysynthetic twinning. On a microscopic scale, the development of double twinning and Albite-Carlsbad law is also distinguished.

The pyroxene group is represented mainly by augite and lesser by orthopyroxenes. In the gabbroic facies, they represent about 30% of the thin section. The augite, with brownish tones and not pleochroic, has subhedral to anhedral shapes. Present very marked longitudinal cleavage planes within which the concentration of opaque minerals and the development of polysynthetic twins are common characterize it. Pyroxenes often surround anhedral olivines with irregular contacts. Locally, they are transformed to amphibole and chlorite at their edges in contact with plagioclase, even generating chlorite pseudomorph.

Orthopyroxenes have subhedral to anhedral shapes with concave-convex contacts with plagioclase, corrosion zone and net contacts, or with narrow reaction rim, with olivines and plagioclases. They are slightly pleochroic in reddish tones (possibly being hypersthene) and occasionally present undulose extinction.

Olivines represent about 15% of the thin section in gabbroic facies, are intensely fractured, with a non-pleochroic colorless to light amber color, with longitudinal subhedral to elongated or rounded anhedral shapes (Figure 8E). With different degrees of transformation, they even generate pseudomorphs of talc and opaque minerals, being able to appreciate old euhedral shapes.

The observable fracturing in the mineral assembly shows a set of fractures that only affect olivines, while another set of fractures also affect plagioclase and pyroxenes.

The fine subhedral shapes observed respond to significant fracturing, recrystallization of plagioclase and transformation to sericite. The fractures are generally coincident with the conjugate planes of weakness of the plagioclase, whereas the discordant fractures are filled with carbonate. On the other hand, it is possible to observe signs of recrystallization in the matrix, since subgrains with lobate edges and undulose extinction are generated.

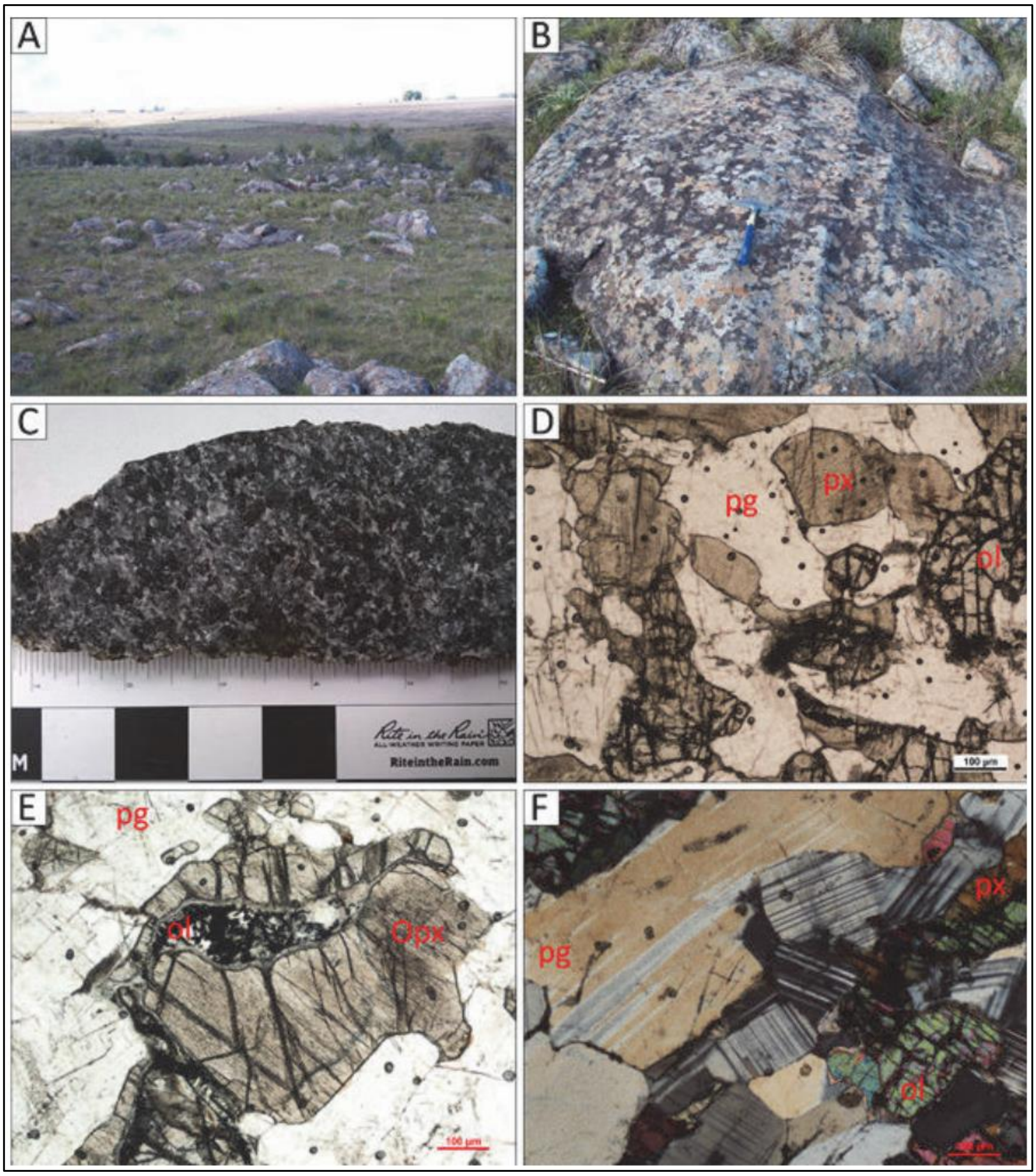

Figure 4. Taken from Curbelo *et al*., 2019. A) General view of the outcrop. B) Plan view of the banded marked by differential erosion. C) Hand specimen of the predominant lithology. D) Thin section showing the general texture of the rock, with the mineral assembly composed of plagioclase, clinopyroxene and olivine. E) Thin section showing in detail olivine, which present an incipient transformation, turned to talc pseudomorphs, immersed in orthopyroxene crystal. F) Thin section showing plagioclase crystal with deformation twings.

Structural and geophysics features

The Cerros Negros complex presents a certain degree of deformation evidenced on a microscale by undulose extinction and incipient recrystallization (by bulging) of plagioclase in contact with pyroxenes, as well as deformation twins and deformed crystals (see curved mineral in Figure 8F). At mesoscale, next to the Cerros Negros public school, it is possible to observe an outcrop habit (intensely weathered) in shape of "*blades with penetrative schistose foliation and anastomosed planes with strike of N092 that surrounds isotropic relics of more* *brittle behavior against deformation*." (Curbelo et al., 2019). These outcrops are close to an E-W lineament, visible in the magnetometric maps (first derivative, second derivative) made during the aeromagnetic and radiometric survey over Uruguay for DINAMIGE (see Figure 5C).

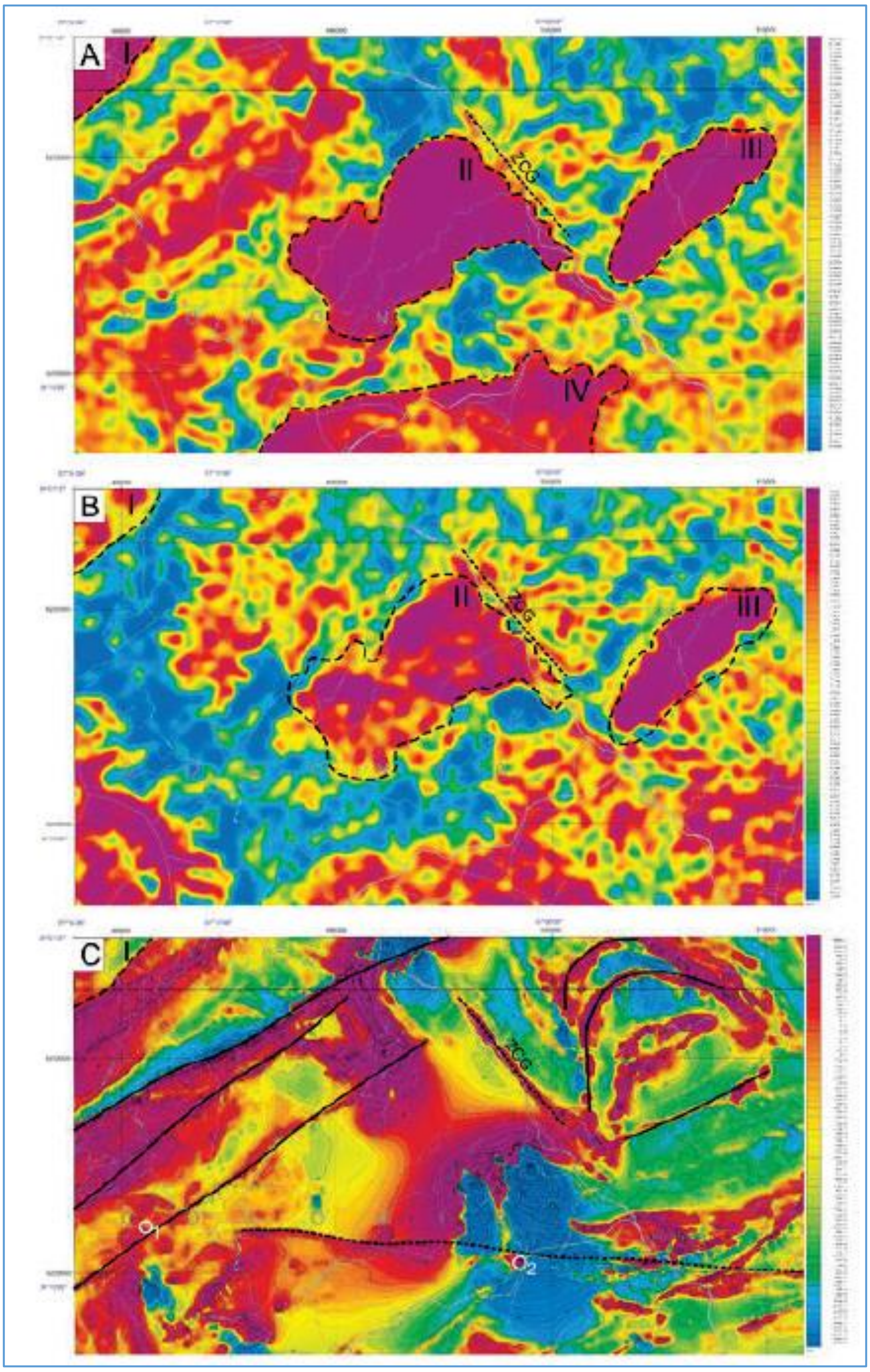

Figure 5: Taken from Curbelo *et al.*, 2019. A) Total Potassium concentration (%). B) Total Thorium concentration (ppm). C) Reduced to the pole anomalous magnetic field (nT). The main lineament of the area (O1), are indicated in solid lines. An incipient lineament (O2) and the Guaycurú Shear Zone -with a strike NW-SE-, are indicated in dashed lines. The main units and structures are also represents in A and B maps, as: I-Cañada de la Cruz Granite, II-Mal Abrigo Granite, III-Mahoma Granite, IV- Porphyritic Granite, ZCG- Guaycurú Shear Zone.

5. CERROS NEGROS GEOCHEMISTRY

It is important to highlight that, the main goal of the *Cerros Negros Prospecting Project* was focused on the search for metallic minerals. The analytical equipment that was possessed in the laboratories, at that time, only allowed analysis for 22 elements, not including Al, Ca or Na. The elements that were not included, if they are of interest, could be analyzed with current analytical techniques.

In the area of Cerros Negros complex, four zones with occurrences of metallic minerals have been recognized. In each of these areas, a sampling was made for chemical analysis of minor elements, either in general samples or in profiles with samples by levels, as a quickly way to recognize them. The occurrence of metallic minerals is concentrated in two lithologies, namely:

- First occurrence can be observed in hornfels.
- Second occurrence is located in lithologies of Paso Severino Formation.

Regarding to mineralization on Paso Severino Formation (predominantly pyrite sulfides), the genesis of hornfels is not clear. These hornfels may correspond to contact metamorphism of leucogabbro of Cerros Negros complex, or with its contribution, or it may have its origin in some other event, perhaps related to Paso Severino Formation.

This hornfels are fine-grained, greenish gray, very compacted and very resistant, with schistose structure to NW. They constitute the Cerros Negros ("Negros Hills") as a landform and outcrop as a narrow strip in contact with the Mal Abrigo granite and the gabbro outcrops, in apparent continuity with those of Paso Severino Formation.

The hornfels have a granoblastic texture as a distinctive feature, due to its mineralogy composed of plagioclase (labradorite), pyroxene (orthopyroxene and clinopyroxene), and secondary green amphibole, as essential minerals. Their outcrops, although they are in contact with Cerros Negros complex, also appear between lithologies of Paso Severino Formation.

Metallic mineral occurrences are in turn very close to the mentioned lithologies of Paso Severino Formation, where it is in contact with the Mal Abrigo granite (1-2 km southeast of the first one). This mineralization on Paso Severino Formation at first glance it seems to be stratiform, the same for the hornfels, which is apparently related to shearing. The two could be related.

At below we present a synthesis of the analytical results of the sampling carried out on the gabbro and hornfels rocks.

CERROS NEGROS GABBRO

VAR	MIN	MAX	MED
Fe	3.5	8.5	6.0
Ba	65	328	174
P	247	820	533
Cu	6.0	211	44
Cr	34	168	92
Ag	0.0	0.3	1.0
B	0.0	9.0	3.2
Zn	6.0	92	57
Sb	0.0	3.0	0.5
Pb	0.0	0.0	0.0
Sn	0.0	5.0	1.5
Ni	30	152	66
V	88	338	152
Mn	581	1334	940
Be	0.0	0.0	0.0
Mo	0.0	2.0	0.1
As	0.0	8.0	2.9
W	0.0	4.0	0.5
Co	19	57	37
Y	5.0	19	10
Cd	0.0	0.0	0.0
Nb	0.0	2.0	0.1

HORNFELS

VAR	MIN	MAX	MED
Fe	5.7	9.0	7.0
Ba	45	258	134
P	123	1001	599
Cu	18	212	58
Cr	21	298	110
Ag	0.0	0.3	0.1
B	0.0	0.0	0.0
Zn	43	99	68
Sb	0.0	8.0	0.8
Pb	0.0	0.0	0.0
Sn	0.0	0.0	0.0
Ni	11	99	47
V	22	278	206
Mn	968	1500	1226
Be	0.0	1.0	0.06
Mo	0.0	1.0	0.3
As	0.0	7.0	2.3
W	0.0	189	11.2
Co	32	50	39
Y	7.0	24	16
Cd	0.0	1.0	0.06
Nb	0.0	0.0	0.0

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