ALUMINIUM IN IBEROAMERICA: MINERAL DEPOSITS AND MINING PRODUCTION IN PORTUGAL

Report prepared by LNEG (Laboratório Nacional de Energia e Geologia) for the Metallogenetic Expert Group of ASGMI (Asociación de Servicios de Geologia y Minería Iberoamericanos)

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Introduction

Portugal is one of the European countries with the longest and stronger mining traditions. Given the richness of the Iberian Peninsula in mineral resources and the favourable conditions for mineral deposits discovery, has allowed these to be exploited from before the Roman occupation of the peninsula.

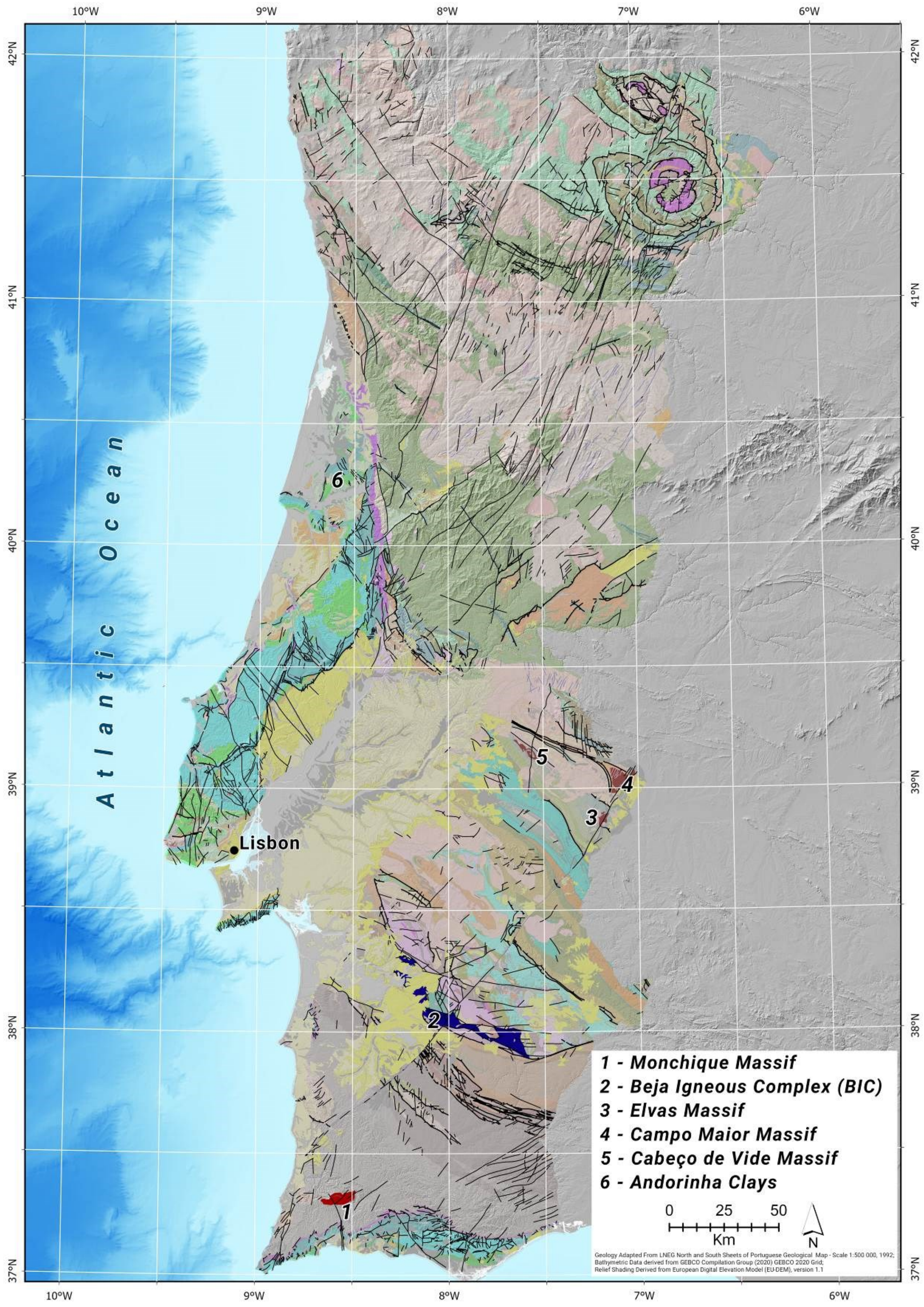
Portuguese mineral resources associated with VHMS-type mineralizations in the Iberian Pyrite Belt (IPB), such as Cu, Zn and Pb and strategic, high-tech minerals like In, Ge and Se, stand out. In the IPB there are two active mines (Aljustrel and Neves-Corvo) and dozens of mining exploration projects.

Equally important are the W and Sn mineralizations in the center and north of Portugal where the Panasqueira mine stands out, producing tin, tungsten and copper concentrates in the last hundred years.

The latest European policies to implement for the EU Green Deal (COM/2019/640 final) and e-mobility, lithium (Li) has assumed a prominent role in the Portuguese economy where the country holds one of the largest European reserves and is currently the 6th world producer according to 2019 figures.

Portugal also contains important Fe, Au and U deposits and a worldwide thriving market in industrial minerals and rocks such as ornamental stones (limestones, marbles, granites and their variations) and common and special clays.

Portugal is not an aluminium producing country, nor does it have bauxite-type mineralizations, the most important aluminium source that reaches international markets. However, over the past few decades, several studies have been carried out in view of the use of some known geological resources for potential aluminium production. Among all of them, studies undertaken in the 70s and 80s of the last century evaluated the Monchique nepheline syenites (SW Portugal; Fig. 1) for aluminium production. In the Andorinha area (center of Portugal; Fig. 1) hyperaluminous clays were evaluated. However, the deposit proved not to be economically viable because of insufficient reserves. Anorthositic areas have not been evaluated for potential aluminium production. However, small anorthositic and/or anorthositic gabbros belonging to the Beja Igneous Complex (BIC) and Campo Maior, Elvas and Cabeço de Vide massif (Fig.1) occur in the Ossa Morena Zone (S Portugal).



Geology Adapted From LNEG North and South Sheets of Portuguese Geological Map - Scale 1:500 000, 1992;
Bathymetric Data derived from GEBCO Compilation Group (2020) GEBCO 2020 Grid;
Relief Shading Derived from European Digital Elevation Model (EU-DEM), version 1.1

Fig.1 – Geological Map of Portugal (adapted from LNEG of 1: 500 000 Geological Map, 1992) with the indication of the areas previously studied and evaluated for potential aluminium production and the anorthositic areas.

The LNEG databases

LNEG has been developing a national information system about the mineral occurrences and resources as well the areas with mining potential that is termed the: “Information System of Portuguese Mineral Occurrences and Resources”

The main objectives that led to the development of SIORMINP (- Sistema de Informação de Ocorrências e Recursos Minerais Portugueses) were to improve the geoscientific, technical and economic knowledge of the mineral deposits; promote the mining development within the national territory by selecting and diffusing information to exploration companies of areas with mining potential; contribute to territorial planning (Fig.2).

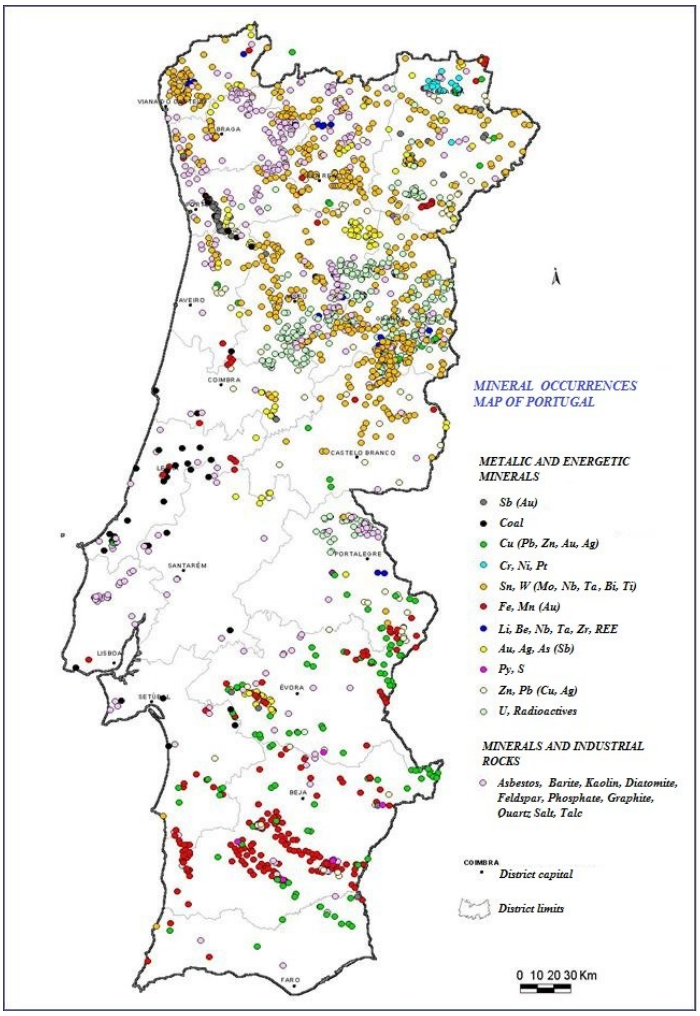
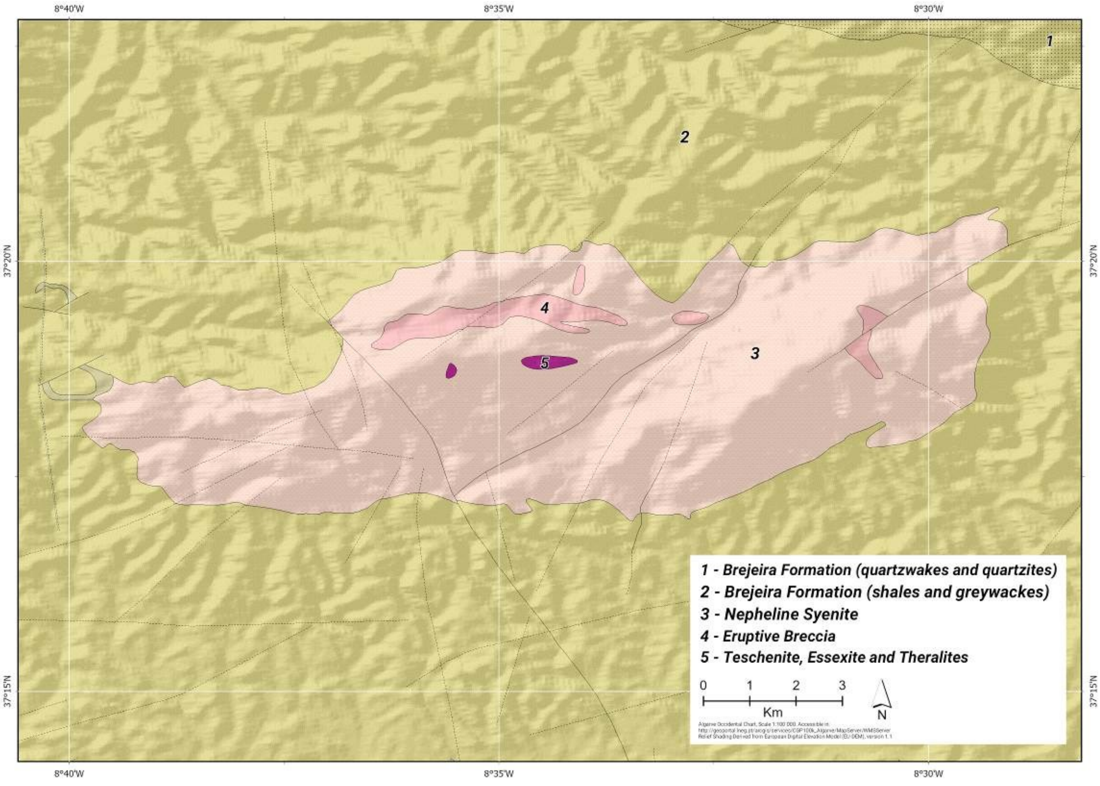


Fig.2 – Portuguese mineral occurrences and resources SIORMINP.

Potential study areas for aluminum exploration

Monchique nepheline syenites

The Monchique syenite massif outcrops over an area of 63 Km^2 (Fig. 3) and corresponds to a high-level laccolithic intrusion belonging to a latest Cretaceous alkaline Province in the Iberian Peninsula (Rock, 1982). It is composed mainly of nepheline syenites (varying irregularly from foyaites to pulaskites), but many other alkaline rock-types are also present, such that there exists overall a reasonably continuous compositional spectrum between ultrabasic and highly evolved felsic rocks. It is therefore an excellent intrusion to study the evolutionary behaviour of different minerals. Various aspects of the geology, petrology, geochemistry and petrogenesis of the complex have already been published (Rock 1976, 1978, 1979, 1983)



Algarve Occidental Chart, Scale 1:100 000. Accessible in: http://geoportal.lneg.pt/arcgis/services/CGP100k_Algarve/MapServer/WMSServer
Relief Shading Derived from European Digital Elevation Model (EU-DEM), version 1.1

Fig.3 – Geological Map of the Monchique Massif (Geological map adapted from Algarve W Chart, scale 1: 100 000 of LNEG)

In the 80s of the last century, the exploration and research project "*Projeto Sienitos Nefelínicos – Monchique*" carried out by the Empresa de Desenvolvimento Mineiro (EDM) the Monchique massif was assessed for its potential for raw materials for the ceramics and glass industries. Throughout this project, detailed geological mapping was carried out, with a view to evaluate what areas inside the massif with a higher nepheline concentration more promising for higher aluminium contents. The project identified two types of nepheline syenites, 1-white nepheline syenite and, 2-pink nepheline syenite, whose chemical analyses are shown in Table 1.

Table 1 – Chemical analyses of the two types of nepheline syenites. Oxides in percentage. Analytical data from "*Projeto Sienitos Nefelínicos – Monchique – Relatório de atividades do 1º semestre de 1990* – EDM)

Rock type	n	SiO_2	Al_2O_3	K_2O	Fe_2O_3	TiO_2	MnO
White Syenite	25	61.1	21.9	5.8	2.7	0.40	0.25
Pink Syenite	11	62.1	21.5	5.8	2.8	0.47	0.25

In this project, the EDM carried out an extensive drill hole campaign to evaluate the quality of nepheline syenites at depth. Approximately two dozen drill holes were carried out and the cores analysed for Fe_2O_3, Na_2O, Al_2O_3, SiO_2 and K_2O. One geological section is represented in the Figure 4 and the analytical geochemical data from three drill holes (Table 2). Results indicate 2 200 000 t of nepheline syenite, but the entire massif was not evaluated.

Coelho (1977) also had the goal to use of nepheline syenite for aluminium production, reviewing the chemical process of aluminium extraction from nepheline. In this study nephelines from syenites are analyzed (Table 3).

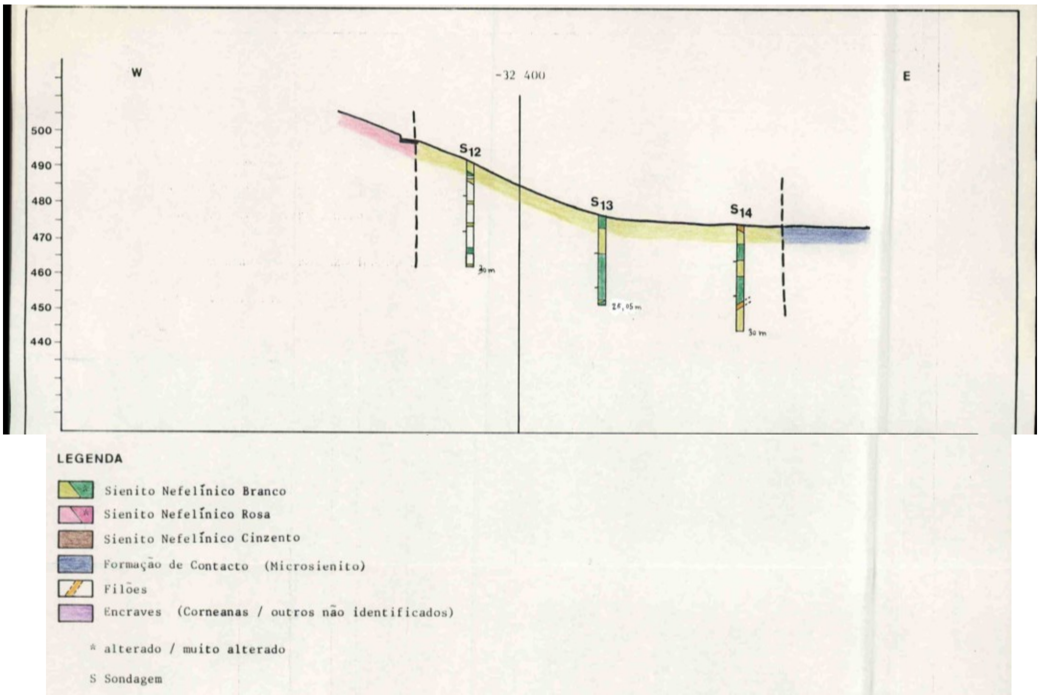


Fig. 4 – Schematic representation of 3 drill holes carried out in the Monchique massif (EDM, 1990)

Table 2 – Chemical analyses of 3 drill holes. Oxides in percentage. Analytical data from "*Projeto Sienitos Nefelínicos – Monchique – Relatório de atividades do 1º semestre de 1990* – EDM)

Drill hole	Meters	Lithology	Fe_2O_3	Na_2O	Al_2O_3	SiO_2	K_2O
S12	7.5-12.5	White syenite	2.3	4.06	21.21	60.27	5.96
S12	13.25-18.70	White syenite	2.95	7.43	21.14	61.68	6.13
S12	24.30-25.10	White syenite	2.06	5.53	21.14	60.71	6.31
S13	4.85-5.15	White syenite	2.23	6.08	20.79	58.18	5.56
S13	9.90-10.10	White syenite	2.07	7.32	20.28	58.87	5.79
S13	12.80-15.45	White syenite	2.40	4.96	21.74	56.28	4.96
S13	18.00-22.00	White syenite	2.20	6.05	21.11	60.69	6.27
S13	24.80-25.05	White syenite	2.40	5.67	20.98	57.77	5.51
S14	5.00-6.30	White syenite	2.55	3.74	21.04	56.94	5.46
S14	9.90-10.10	White syenite	2.32	11.14	20.07	58.48	6.01
S14	14.90-15.10	White syenite	2.29	6.39	21.04	53.29	4.05
S14	17.50-20.50	White syenite	2.60	4.5	20.32	56.60	4.98
S14	25.00-25.20	White syenite	2.36	7.07	20.87	59.27	5.57
S14	29.80-30.00	White syenite	2.35	8.28	20.84	57.26	5.62

Table 3 - Chemical analyses of nepheline from nhepheline syenite. Oxide in percentage. Data from Coelho 1977

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	H_2O
45	30	2.5	1.0	0.6	14	4.5	0.8	0.7

Anorthositic areas

Beja Igneous Complex (Layered Gabbroic Sequence)

The Layered Gabbroic Sequence (LGS) is part of the Beja Igneous Complex (BIC), a prominent geological feature of the SW Iberian Variscides (Ribeiro et al., 2007) that extends ca. 100 km along the OMZ SW border in Portugal. It consists of three main units (Andrade, 1983) developed during different stages of the oblique collision between the OMZ upper plate and South Portuguese Terrane lower plate (Jesus et al., 2007) namely: (1) the LGS, representing the early stages of collision magmatism; (2) the Cuba–Alvito (gabbro-diorite) Complex recording late-collision magmatic activity; and (3) the Baleizão Porphyry Complex documenting post-collision magmatism (Fig. 5) (Jesus et al., 2014).

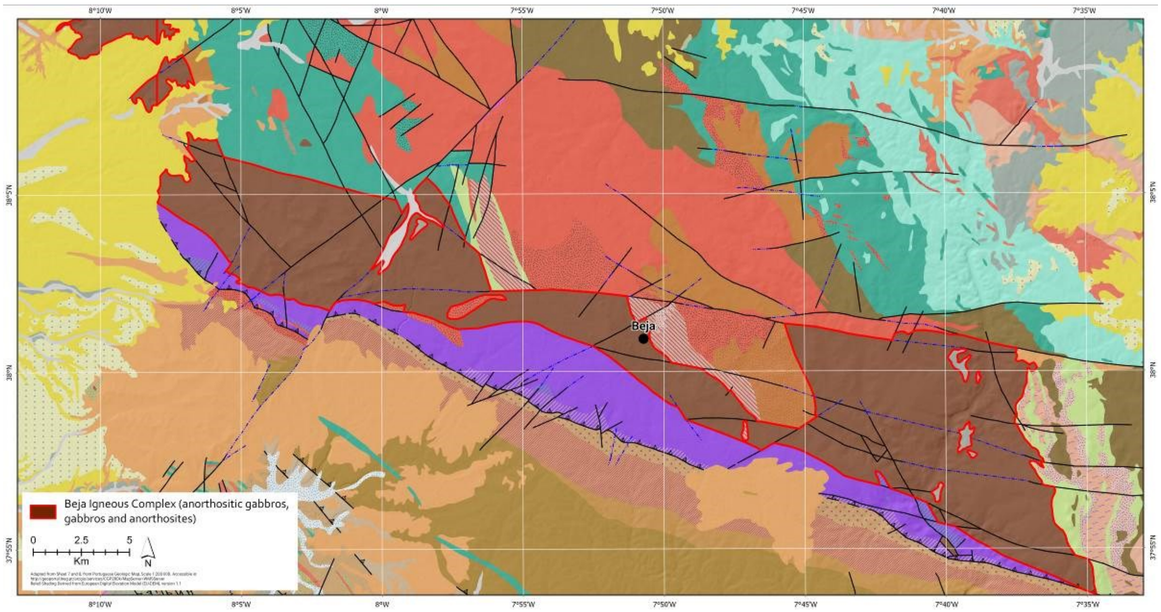


Fig.5 – Geological Map of Beja Igneous Complex (Geological map adapted from 1:200 000Sheets 7 and 8 of Portuguese Geologic Map)

The first reference of the existence of a zoned anorthosite structure in the Beja Igneous Complex (BIC) appears in a work by Silva et al., 1970. Anorthositic bands were identified with thicknesses varying from a few centimeters to 1.5 meters, with light-grey color, medium grained and interspersed between gabbros, olivine gabbros and hypersthenic gabbros. Under the microscope, feldspar bands are formed by labradorite plagioclase type with 52-59% of anorthite.

Through detailed geological mapping, Jesus (2011), identified small anorthositic bodies in the LGS (Fig.6). The same author undertook an exhaustive mineral chemistry study of the plagioclases found in each level (Table 4).

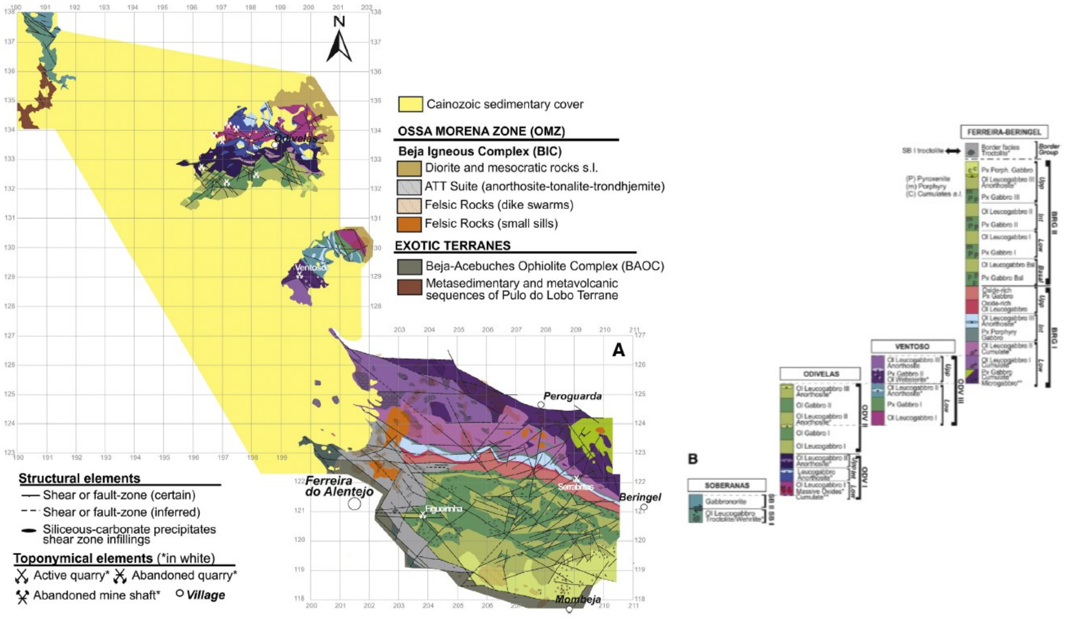


Fig. 6 – Simplified geological map of the western compartment of the LGS (After Jesus, 2011; Jesus et al., 2014)

Table 4 – EPMA analysis from plagioclases of anorthosites. Areas: ODV – Odivelas; BRG – Beringel; Analytical data from Jesus, 2011

Area	ODV	ODV	ODV	ODV	ODV	ODV	ODV	BRG	BRG	BRG	BRG	BRG	BRG	BRG	BRG
SiO_2 (%)	55.03	55.51	55.84	54.78	54.08	53.12	53.95	52.17	52.98	51.68	49.14	50.53	49.53	49.27	49.38
Al_2O_3 (%)	27.11	27.99	28.00	27.62	29.24	29.70	29.49	30.60	30.03	30.87	32.38	31.89	32.10	32.45	32.55
FeO_t (%)	0.21	0.33	0.32	0.28	0.23	0.39	0.43	0.20	0.27	0.39	0.31	0.35	0.25	0.22	0.30
CaO (%)	10.35	10.55	10.31	10.22	11.68	12.35	11.93	12.54	12.20	12.82	14.58	14.48	14.28	14.74	14.79
Na_2O (%)	5.52	5.08	5.37	5.13	4.95	4.26	4.48	4.26	4.61	4.06	2.83	3.31	2.92	2.94	2.92
K_2O (%)	0.25	0.24	0.24	0.22	0.24	0.19	0.20	0.14	0.19	0.17	0.00	0.00	0.21	0.08	0.00
Atoms per formula unit															
Si	10.07	10.02	10.04	10.03	9.74	9.62	9.71	9.47	9.58	9.39	9.02	9.16	9.09	9.02	9.01
Al	5.85	5.95	5.93	5.96	6.21	6.34	6.25	6.54	6.40	6.61	7.01	6.81	6.94	7.00	7.00
Fe^{3+}	0.03	0.05	0.05	0.04	0.03	0.06	0.07	0.03	0.04	0.06	0.05	0.05	0.04	0.03	0.05
Ca	2.03	2.04	1.99	2.00	2.25	2.40	2.30	2.44	2.36	2.49	2.87	2.81	2.81	2.89	2.89
Na	1.96	1.78	1.87	1.82	1.73	1.49	1.56	1.50	1.61	1.43	1.01	1.16	1.04	1.04	1.03
K	0.06	0.06	0.06	0.05	0.06	0.04	0.05	0.03	0.04	0.04	0.00	0.00	0.05	0.02	0.00
Or (%)	1	1	1	1	1	1	1	0.81	1.06	1.01	0.00	0.00	1.26	0.47	0.00
Ab (%)	48	46	48	47	43	38	40	37.75	40.15	36.07	26.00	29.26	26.68	26.42	26.33
An (%)	50	53	51	52	56	61	59	61	59	63	74	71	72	73	74

Campo Maior, Elvas and Cabeço de Vide Massifs

The Campo Maior, Elvas and Cabeço de Vide Massifs corresponds to calc-alkaline plutonic magma bodies that were intruded into high-grade Upper Proterozoic / Lower Paleozoic rocks near the northeastern boundary of the Ossa-Morena Zone (Fig.7) (Lopes et al., 2005).

There are several controversies about the real composition of these massifs. However, in the 1/ 50 000 geological maps (Sheets 32 – B Portalegre; 32 – D Sousel; 33 – C Campo Maior; 37 – A Elvas) the rocks of this massifs are characterized as hypersthenic rocks with a large lithological spectrum, ranging from pyroxenites, anorthosites and gabbros (predominant) to monzonites/diorites and granodiorites. From the above mentioned three massifs, from a petrography and geochemistry (Table 5) point of view, the Campo Maior Massif is the best studied, Lopes et al. (2005).

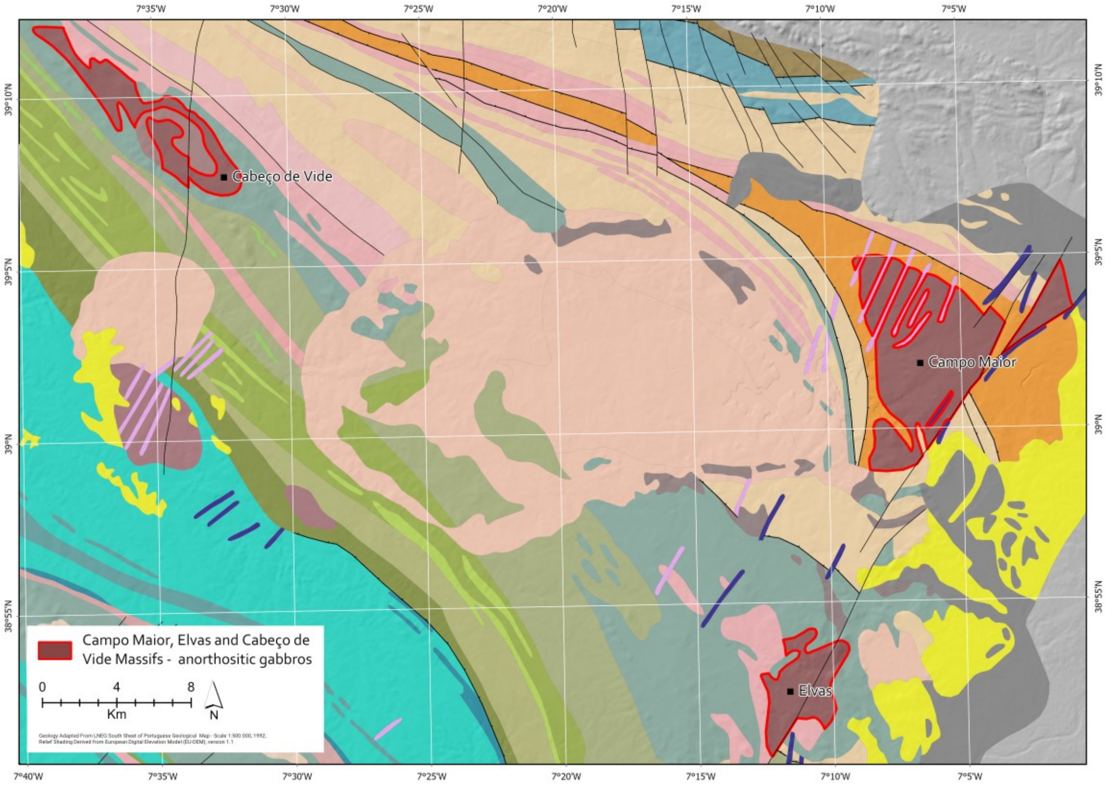


Fig.7 - Geological Map of the Campo Maior, Elvas and Cabeço de Vide massifs (Geological map adapted from 1/ 500 000 sheet)

Table 5 – Representative chemical analysis of feldspars of Campo Maior Massif. G-opx – gabbros with ortopyroxene; ANRT – Anorthosites. Chemical data from Lopes et al., 2005

Lithotype	G-opx	G-opx	G-opx	ANRT	G-opx	G-opx
SiO_2 (%)	47.87	55.12	49.96	48.24	47.62	47.68
Al_2O_3 (%)	32.94	28.04	31.72	32.21	33.27	32.56
FeO_t (%)	0.13	0.05	0.19	0.25	0.17	0.26
CaO (%)	16.47	10.94	14.83	15.69	16.58	16.16
Na_2O (%)	2.11	4.85	2.90	2.58	2.01	2.21
K_2O (%)	0.03	0.17	0.13	0.10	0.11	0.07
Si	8.814	10.000	9.139	8.923	8.759	8.838
Al	7.148	5.995	6.838	7.022	7.212	7.113
Fe^{2+}	0.020	0.008	0.029	0.039	0.026	0.040
Ca	3.249	2.127	2.906	3.109	3.267	3.209
Na	0.753	1.706	1.029	0.925	0.717	0.794
K	0.007	0.039	0.030	0.024	0.026	0.017
Or (%)	0.18	1.02	0.77	0.58	0.64	0.41
Ab (%)	18.79	44.06	25.94	22.80	17.88	19.76
An (%)	81.04	54.92	73.30	76.62	81.48	79.83

Hyperaluminous clays

In the Coimbra region, center of Portugal, and covering the Andorinha limestone's (Bajocian – Bathonian), occur white hyperaluminous clays (Gomes, 1965, 1966, 1968, 1970). These are small occurrences with production below 400 ton/year. In 1965 and 1977 chemical analyses were carried out on these clays. These are presented in Table 6.

Table 6 - Representative chemical analysis of the Andorinha clays

	Sample 1	Sample 2	Sample 3	Sample 4
SiO_2 (%)	40.88	41.94	35.08	75.96
Al_2O_3 (%)	36.46	37.46	43.36	13.38
Fe_2O_3(%)	3.72	2.77	4.33	1.17
TiO_2 (%)	3.28	2.48	0.82	0.87
CaO (%)	0.66	0.63	0.00	1.45
MgO (%)	0.13	0.15	0.00	0.00
Na_2O (%)	0.00	0.00	0.00	0.49
K_2O (%)	0.17	0.08	0.23	0.29

Concluding Remarks

Portugal has never had aluminium production: however, several locations have been studied to evaluate their aluminium contents. By far the best studied is the Monchique nepheline syenite and although the aluminium content in total rock and nepheline minerals are interesting, further detailed studies (and very favourable economic conditions) are necessary to elevate this massif to a deposit.

The small size of the Andorinha clays and low Al-contents makes them uneconomic.

The known anothositic areas are poorly studied and need more detailed geological studies to understand the size and potential of the resource.

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COM/2019/640 final, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS The European Green Deal.