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## Critical Raw Materials Deposits Map of Mainland Portugal: New Mineral Intelligence in Cartographic Form

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### ABSTRACT

Reliable and unhindered access to raw materials is a growing concern within the EU and across the globe and the demand for Critical Raw Materials (CRM) plays a crucial economic role in most developed countries around the world. These are of extreme importance for supply chains regarding new technologies, sustainability issues and carbon footprint reduction. The definition of a continuously updated list of CRM by the European Commission led to the first CRM Map of Europe in 2016. Following this, several countries have been surveying, preparing, and evaluating their mineral occurrences to create a resources/deposits database and, therefore, to create a CRM map of their own. With this purpose in mind, we present and explain the first Critical Raw Materials Deposits Map of mainland Portugal, at 1:700,000 scale. This paper describes the scientific, technical, and graphical methodologies involved in its design.

### KEYWORDS

Critical raw materials; occurrences; mainland Portugal; geology; official geological mapping; mineral intelligence

## Introduction

Europe's intention to become the world's first climate-neutral continent by 2050 means the implementation of the 'European Green Deal' by the European Commission and involves a collective effort. Measures accompanied with an initial roadmap of key policies range from ambitiously cutting emissions, to investing in cutting-edge research and innovation, and to preserving Europe's natural environment (COM/2019/640 final). It is accepted that non-energy minerals underpin modern economies since they are essential for manufacturing and renewable energy supplies (e.g. COM(2008) 699 final; de Oliveira *et al.* 2020a, 2020b; Wittenberg *et al.* 2020a, 2020b; IEA 2021) and domestic production is a key factor in improving the security of supply of raw materials to the European Union's economy (European Commission, 2018a).

The twentieth century saw a shift from agrarian to industrialized societies, together with a growing world population and changing consumption patterns, which has led to a significant increase in global demand for raw materials. Projections of future trends indicate that resource use could double between 2010 and 2030, mostly driven by demand in developing regions (European Commission, 2016). The critical question is whether supply to meet these demands is adequate. Access to sustainable resources is key for the EU's resilience in relation to raw materials. Achieving resource security requires action to diversify supply from both primary and secondary sources, reduce dependencies and to improve resource efficiency and circularity, including sustainable product design. This is true for all raw materials but is vital when it concerns those raw materials that are considered critical for the EU.

European industry is dominated by the manufacturing sector (i.e. the manufacture of end products and applications) and the refining industry (e.g., metallurgy), compared to the extractive industry (e.g., mining and carriers) (European Commission, 2018b). Import reliance for certain materials considered to be critical for the EU economy remains close to 100%. This dependency corresponds to lower security of supply, especially when combined with highly concentrated primary production in non-EU countries that have low levels of governance (European Commission, 2018a). Restricting measures on exports of raw materials commodities have been increasingly used by supplier countries over the last years, and hence the high import dependence of critical raw materials (CRM) as well as strategic raw materials (SRM) has a serious negative impact on the sustainability of the EU manufacturing industry value chains and key enabling technologies (e.g. defence, renewable energy industry, automotive industry and AI), as well as a significant carbon footprint associated to foreign ore transport. A knowledge of Europe's subsurface and the potential mineral supplies that can be used in these manufacturing industries can achieve this. Effectively, the analysis of existing spatial data is fundamental to allow geologists to go from the known deposits (brownfield exploration targets), and

available data, to the yet unknown (greenfield exploration targets) and potential deposits. For this to happen, the spatial data need to be spatially analysed, in the first instance as a whole, and no tool is better suited for this than a comprehensive map. This paper focuses on the development and concept of the first Critical Raw Materials Deposits Map for mainland Portugal.

### What is the 'criticality' of raw materials?

The two main parameters for determining criticality are economic importance (EI) and supply risk (SR) and are used to determine the criticality of the material for the EU. Critical Raw Materials are determined on the basis of the raw materials which reach or exceed the thresholds for both parameters (Deloitte Sustainability *et al.*, 2017). For the EU, CRM are those which display a high risk of supply shortage in the next ten years, and which are economically and strategically important for specific value chains. The mineral supply risk is linked to the concentration of production in a few non-European countries (e.g., USA [Beryllium, Helium), Brazil [Niobium], DRC [Cobalt], Rwanda [Tantalum], South Africa [Iridium, Platinum, Rhodium, Ruthenium], Russia [Palladium] and China (all CRM) (European Commission, 2018b: Figure 3), and the low political-economic stability of some of the suppliers. This risk is compounded by low substitutability and low recycling rates (COM/2011/0025 final). Apart from the high-risk associated with their supply, CRM are so important because they are 'critical' for the EU's mega-sectors and for a wide range of commercial and governmental applications: green technologies, telecommunications, space exploration, aerial imaging, aviation, medical devices, micro-electronics, transportation, defence, and other high-technology products and services.

The EU Commission has, since 2011, been concerned with the supply risk of these raw materials and has published regular lists of CRM. The first list was published in 2011 (COM/2011/0025 final), the second in 2014 (COM/2014/0297 final), the third in 2017 (COM/2017/0490 final) and the latest in 2020 (COM/2020/474 final). Based on these reports, Table 1 summarizes the different commodities updated in these lists.

### The SIORMINP database

The SIORMINP database ('Information System of Portuguese Occurrences and Mineral Resources') has been developed by the Laboratório Nacional de Energia e Geologia (LNEG) as a database system about the mineral

**Table 1.** Europe critical raw materials list from 2011, 2014, 2017 and 2020.

Critical raw material	2011	2014	2017	2020
Antimony (Sb)	X	x	x	X
Baryte (Ba)			x	X
Bauxite				X
Beryllium (Be)	X	x	x	X
Bismuth (Bi)			x	X
Borates		x	x	x
Chromium (Cr)		x		
Cobalt (Co)	x	x	x	x
Coking Coal		x	x	x
Fluorospa	x	x	x	x
Gallium (Ga)	x	x	x	x
Germanium (Ge)	x	x	x	x
Hafnium (Hf)			x	x
Helium (He)			x	
Indium (In)	x	x	x	x
Lithium (Li)				x
Natural Graphite	x	x	x	x
Natural Rubber				x
Magnesium (Mg)	x	x	x	x
Niobium (Nb)	x	x	x	x
Phosphate rock		x	x	x
Phosphorus			x	x
PGM <sup>(*)</sup>	x	x	x	x
Rare Earth Elements	x	x	x	x
Scandium (Sc)			x	x
Silicon Metal		x	x	x
Strontium (Sr)				x
Tantalum (Ta)	x		x	
Titanium (Ti)				x
Tungsten (W)	X	x	x	x
Vanadium(V)			x	x

Source: COM/2011/0025 final, COM/2014/0297 final, COM/2017/0490 final, COM/2020/474 final.

\*(PGM) – Platinum Group Metals = iridium, osmium, palladium, platinum, rhodium and ruthenium.

occurrences and resources and areas with mineral potential at the national level. The SIORMINP database started being developed in 1997, with all the inputs to this Information System (IS) taking place between 1997 and 2002, during which mainland Portugal was covered with 2,164 mineral deposits. Today, the IS contains 2,292 records with more being added as new discoveries are made.

The main objectives that led to the development of SIORMINP 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; and contribute to land planning activities.

This IS contains several types and levels of information: general data, geographic and geologic data, economic data, main ore minerals, accessory ore mineralogy, tonnage and concentrate data and, concessionaire's data, in a total of 60 data fields. In almost 25 years, the use of SIORMINP has played a key role in shaping mineral exploration programmes and allowed LNEG to define areas of mineral potential.

## Objectives of the CRM map

CRM maps have been produced in the past in Europe (e.g. Bertrand *et al.*, 2016) and elsewhere (e.g. USGS, 2020) to aid decision-making processes and to highlight (critical/strategic) commodities for specific geopolitical or economic scenarios at a specific point in time. As such, the objectives of the Portuguese map of CRM focus on: (a) promotion of European and worldwide mineral intelligence; (b) providing a basis for visualizing the distribution of CRM in Portugal and relate it with other European counterparts; (c) allowing for a pictorial depiction of the location of occurrence, morphology and type of deposits; (d) augmenting pan-European mineral datasets of CRM, e.g. the European Geological Data Infrastructure (EGDI) and the Raw Materials Information System (RMIS) and improving data sharing; (e) honing methods for validation and model exchange; (f) improving models for conceptual mapping criteria; (g) forming the beginnings of a global database necessary to understand and refine the controls on critical mineral distribution; (h) increasing accuracy in mineral resource assessments; (i) Identifying mineral potential areas for additional mineral supply; (j) promoting new mineral deposit discovery; and (k) promoting communication and outreach.

## Critical raw materials deposits map

Besides the European Commission as a community, several countries, from Europe, America, Oceania and Asia, are working on national CRM distribution and inventories and, in some cases, creating and adapting their own CRM list (e.g. Australia, US, Canada, Japan, South Korea, among others). The first CRM maps of Europe were produced from the ProMine EU Project (2010–2013; see <https://www.eurogeosurveys.org/projects/promine/>). The project's main goal was to deliver an interactive visualization tool with 3D/4D capabilities to display models of European mineral deposits. In December 2015, Version 3 of that map was released (Bertrand *et al.*, 2016) as a follow-up deliverable from EuroGeoSurveys' Mineral Resources Expert Group. Also, the Australian government provided in 2019 a map of major critical minerals with operating and developing mines containing critical commodities (see <https://www.industry.gov.au/data-and-publications/australias-critical-minerals-strategy/the-opportunity-for-the-critical-minerals-sector>). Increasing studies and demands on behalf of the European Commission, economic and geopolitical factors, and the need to reduce the carbon footprint by increasing consumption of renewable energies and e-mobility solutions (IAEA, 2021) have catalysed CRM inventories. This was the impetus for creating the CRM map of mainland Portugal.

Regarding the Portuguese scenario, there are a total of 477 known occurrences related to CRM. In Table 2, all the commodities are listed by district and Figure 1 shows an overview of the spatial distribution of the CRM occurrences in each of the major tectonostratigraphic zones of Iberia (Lotze, 1945; Ribeiro *et al.*, 1990; Quesada, 1991) and political districts of mainland Portugal as obtained from the Official Administrative Map of Portugal (CAOP; see <https://www.dgterritorio.gov.pt/cartografia/cartografia-tematica/caop>).

For the construction of such a map, four different levels of information were taken into consideration:

- (1) The CRM data source – All data were available within the LNEG's SIORMINP database. This was the main source of information for the map of CRM in mainland Portugal and every known occurrence in SIORMINP has a unique identifier.
- (2) The CRM symbology itself – From a cartographic point of view, the visual variables theory (Bertin, 1983) was taken into consideration. Variables such as shape, size, orientation, colour, and value were a concern and essential to better represent the attributes from the data that was used, specifically: commodity, deposit size, deposit genesis and main deposit/mineralization orientation. Other aspects taken into account during

**Table 2.** Commodity listing by district.

Political districts	Commodity	No. of occurrences
1-Aveiro	Antimony	1
	Tungsten	12
2-Beja	Antimony	4
	Barite	10
	Germanium	1
	Indium	1
3-Braga	Antimony	2
	Beryl	1
	Graphite	2
	Lithium	1
	Tantalum/Niobium	1
4-Bragança	Tungsten	12
	Antimony	9
	Barite	2
	Phosphate	2
5-Castelo Branco	Tungsten	51
	Antimony	2
	Barite	4
	Lithium	1
	Lithium + Tungsten	1
	Phosphate	1
	Rare Earth Elements	2
	Titanium	7
6-Coimbra	Tungsten	29
	Antimony	1
	Titanium	4
	Tungsten	2
7-Évora	Antimony	4
	Barite	1
8-Faro	Antimony	1
	Barite	2
	Rare Earth Elements	1
9-Guarda	Titanium	2
	Antimony	1
	Beryl	2
	Lithium	7
	Tantalum/Niobium	3
	Titanium	22
10-Leiria	Tungsten	64
	Tungsten	1
11-Portalegre	Barite	3
	Cobalt	1
	Phosphate	7
	Rare Earth Elements	2
	Titanium	1

the map design phase were the scale and representation of the elements. The representation of several deposits had to be suppressed from the physical version of the map due to the data point density. This problem was addressed in the online version of the map, in which the scale factor is not determinant.

- (3) Geological base map – The 2010 Geological Map of Portugal at 1:1,000,000 scale was used (LNEG, 2010). Besides the main lithology types, the flipside of the map also shows the major tectonostratigraphic zones of Iberia as per Lotze (1945, and modified by Ribeiro *et al.*, 1990; Quesada, 1991). The Paleozoic Zones (Galiza Trás-os-Montes, Central Iberian, Ossa-Morena and South Portuguese zones), and the Mesozoic Basins (Algarve, Alentejo and Western), as well as the recent Cenozoic deposits are represented. This image is shown on the reverse side of the map, where all commodities are organized by political districts. In each of the above-mentioned zones, the major groups, complexes or series are grouped according to their major lithologies including sedimentary, metamorphic and igneous rock types. The magmatic rocks suite in each zone is shown as an independent group, also classified by rock type. Each polygon labelling has specific lettering concerning their specific stratigraphic periods or lithology. The tectonic features were also taken from the same geological map (LNEG, 2010);
- (4) Map background – To provide better depiction of the terrain, the geology was superimposed on shaded terrain relief. Shaded relief is a standard visualization technique for geospatial and height resolution datasets (Veronesi and Hurni, 2015). Hillshade was constructed using the swiss hillshade effect algorithm available in the Esri updated hillshade toolbox (See <https://www.esri.com/arcgis-blog/products/product/mapping/updated-hillshade-toolbox/?rsource=blogs.esri.com/esri/arcgis/2008/10/07/updated-hillshade-toolbox>) and used EU-DEM v1.1 (see <https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1>), as an altimetric data source.

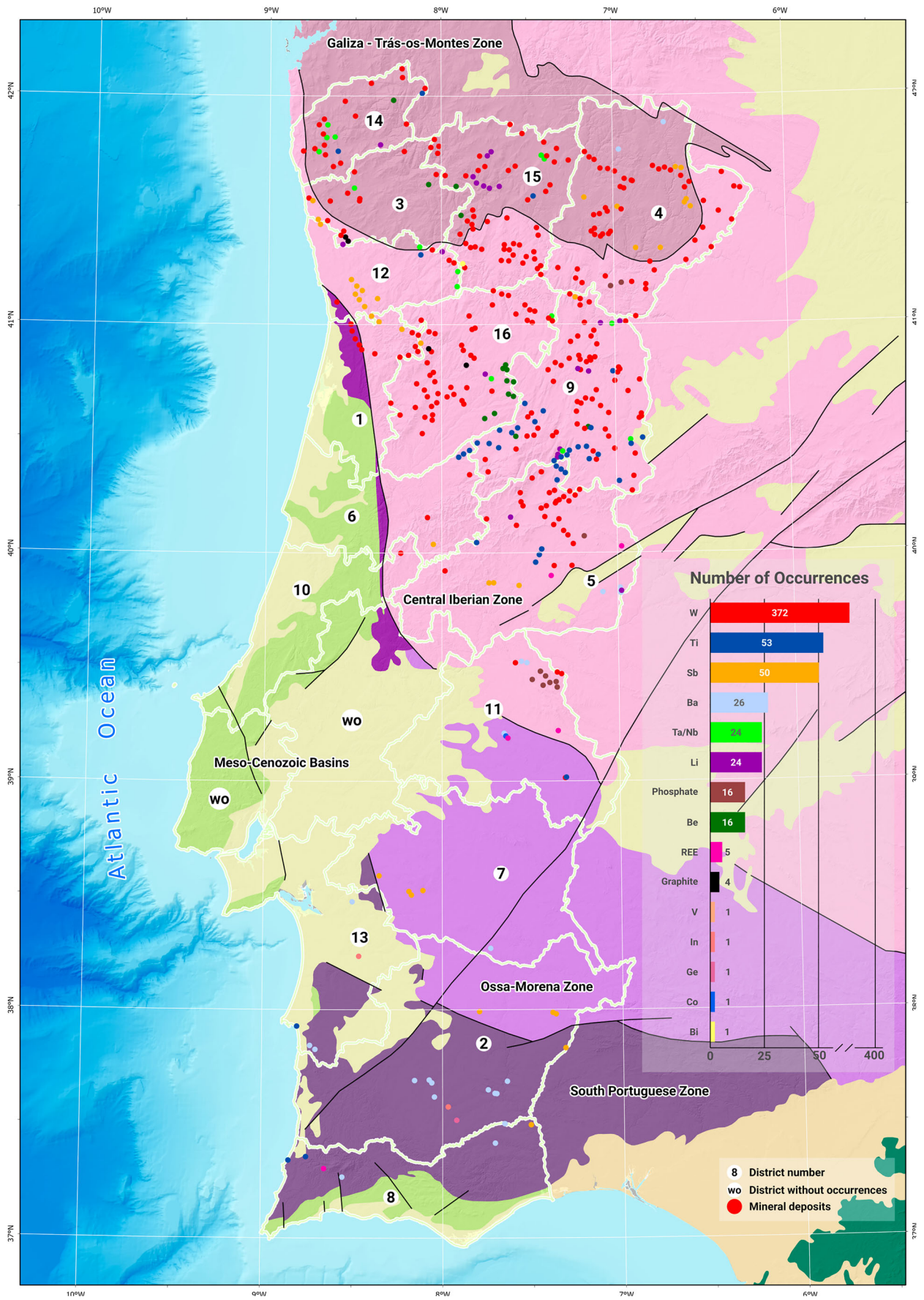


Figure 1. Inset of the main tectonostratigraphic domains and distribution of CRM on mainland Portugal shown on the reverse side of the map (after de Oliveira *et al.*, 2021). The bar graph colours match the colour codes used to locate the occurrences by substance on the main part of the map.

- (5) For bathymetric data, the same procedures were followed and used the GEBCO (See <https://www.gebco.net/>) gridded bathymetric data. The data were smoothed and simplified to provide a better visual representation.

## Methodologies – map design

During the map conception phase, some similar maps and figures were taken into consideration, but a norm or standard to map the different elements presented could not be obtained for elements such as commodity, mineralization source, and so on. A standard could be an important milestone to provide a better overview of data from different countries and an attempt to homogenize data and map symbology such as FGDC Digital Cartographic Standard for Geologic Map Symbolization (USGS, 2006), developed to provide a single US national standard for the digital cartographic representation of geological map features.

The genetic classification of the occurrences of Critical Raw Materials Map of mainland Portugal was based on the Australian classification models of mineral deposits as per the 1:1,500,000 Metallogenic Map of New South Wales (Downes *et al.*, 2011). This was chosen because of the simplicity of displaying complex data in a simple-to-understand graphical context. The first stage was to classify ‘internal’ and ‘external’ source-related deposits, and in particular for the former, to discriminate between full magmatic deposits and geodynamic transitions to hydrothermal, and also metamorphic related deposits.

Table 3 highlights these desegregations showing the mineralization source subdivided into Superficial Processes, Magmatic, Magmatic/Hydrothermal, Metamorphic/Hydrothermal and lastly, Hydrothermal classes. Within each process, a genetically related concept approach is used to include each mineral resource. However, some geodynamic settings favourable for some types of deposits are often affected by several impacting factors such as temperature, pressure, salinity, fluid circulation and other factors turning it into a multi-process environment, and mineral deposit genesis will vary accordingly and are important to consider. Additionally, the same element or commodity can be generated from different processes in different geological environments (see Table 3).

Deposits were also classified by size, which associated with geographic density helps to highlight high mineral resource potential. This size classification (Table 4) was adapted from the deposit size class developed in the ProMine project (Bertrand *et al.*, 2016), and is used internally by LNEG and emphasizes important distinctions among different commodities’ tonnage deposits, as different commodities have different size thresholds (e.g. INSPIRE, 2013).

Each commodity was symbolized in a specific way, but there were some cases that for a given occurrence it was necessary to symbolize using two different colours, as shown in Figure 2, corresponding to two different known elements. For each occurrence, and every time information was present, the outer symbol was given the same direction of the mineralization body, providing further information on the mineralization structure.

Since there are several zones of mainland Portugal that have densely clustered mineral occurrences, some of the symbols (specifically the considered least important mineralization) were simplified. A buffer with a different radius, ranging from 500 to 2,000 m, was computed for each clustered deposit. This buffer was generated based on the size attribute of the deposit and, to avoid further visual noise, it is translucent, using the same colour of the commodity that it represents as shown in Figure 3.

To give mineralization data a relation to the SIORMINP database, labels were used. Each occurrence had a label assigned corresponding to its ID code in the original database. It also provides a connection to the reverse page of the map, providing further elements such as the name of the occurrence, critical raw element detected and morphology of the deposit.

**Table 3.** Classification of resources according to their genesis and mineralization source.

Mineralization Source	Genesis	Resource
Superficial Processes	Alluvial Deposits	W, Ta/Nb, Ti,
	Supergene Enrichment	Ti, W
	Alluvial/Elluvial Deposits	Ti
	Chemical Precipitate	Ba, Phosphates
	Detritic	REE <sup>(*)</sup>
Magmatic	Orthomagmatic	Co, V, REE
Magmatic/Hydrothermal	Aplopegmatites	Be, Ti, Ta/Nb, W, Li
	Skarn/Skarnoid	Li, W
	Hydrothermal Ba	Ba
Metamorphic/Hydrothermal	Metasomatic Processes	W
	Shear Zone Associated	Sb, W
	Hydrothermal	Ba, Be, Bi, Ge, Phosphate, Sb, REE <sup>(*)</sup> , W, Ti, Ta/Nb, Li
Hydrothermal	Metamorphic/Hydrothermal	Graphite
	Volcanogenic Massive Sulphides	In, Ba
	Other Volcanogenic Deposits	Ba, Sb

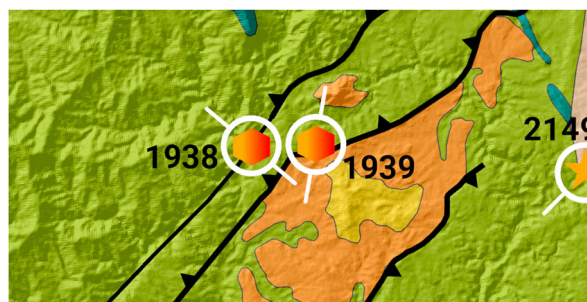
\*REE – Rare Earth Elements.

**Table 4.** Classification of deposit tonnage size criteria for each commodity.

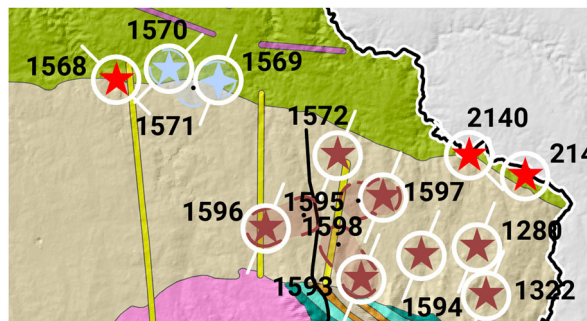
Commodity (t)	Small	Medium	Large
Antimony	<2000	2000–20000	>20 000
Baryte	<50000	†	†
Beryllium	<100	100–1000	>1000
Bismuth	<500	†	†
Cobalt	<200	†	†
Germanium	<5	†	†
Graphite	<50000	†	†
Indium	<5	†	†
Lithium	<150	150–1500	>1500
Phosphate	<50000	†	†
Rare Earth Element	<1500	1500–15000	>15000
Tantalum/Niobium	<10	10–200	>200
Titanium	<1000	1000–500000	>500000
Tungsten	<1000	1000–50000	>50000
Vanadium	<500	†	†

Note: All numbers in metric tonnes (1 tonne=1000 kg); all threshold data as per Inverno *et al.* (2020a, 2020b, 2020c, 2020d, 2020e, 2020f, 2020g, 2020h, 2020i).

†Deposits of these sizes, with these substances, are unknown in Portugal.



**Figure 2.** The use of gradient-coloured symbols in the map highlighting deposits containing both Sb and W (adapted from De Oliveira, *et al.* 2021). North points to the top of the figure.



**Figure 3.** Detail of the Nisa batholith mineralization cluster, East Central Portugal, showing the use of dash outlined translucent buffers visible in the 1595, 1598 and 1571 mineralization ID points. North points to the top of the figure (adapted from De Oliveira, *et al.* 2021).

## Conclusions

Regarding symbology there are more than a hundred combinations of elements using colour (commodity), shape (mineralization source), size (deposit size), and rotation (direction of mineralization structure). The complexity of data available and the scale for the printed map were limiting factors leading to several design choices, specifically the attributes that could be unambiguously represented. The mineralization source was chosen to give additional information on the occurrence and the deposit morphology was described on the reverse page of the map since it was considered relevant and complementary information.

The map *Critical Raw Materials Deposits in Mainland Portugal*, as shown in Figure 4(a,b), is now published and available for download (high resolution) at the LNEG website in PDF format (See <https://www.lneg.pt/en/product/critical-raw-materials-deposits-in-mainland-portugal-2/>), as well as a webmap (See <https://geoportall.lneg.pt/>) version, served through LNEG's geoportall service.

As stated above, this map was developed considering the data from the COM/2020/474 final report, which contains the latest list of CRM and the map will be upgraded/updated every three years following the release







of updated EU CRM lists. The scrutiny of the SIORMINP database necessary to produce this map means the continuous update of the data to produce more complete future versions of this map.

The map *Critical Raw Materials Deposits in Mainland Portugal* represents a leap in mineral intelligence for users in mineral exploration, mineral resource evaluation, land use planning criteria, central and local government decision makers and outreach and education.

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Notes on the contributor



**Daniel P. S. de Oliveira** holds a BSc (1989), BSc (Hons) (1990), MSc (1994) and PhD (2002); the latter in Economic Geology from the University of the Witwatersrand, South Africa. He has experience in South African deep underground mines of the Wits Gold Field, Bushveld Igneous Complex (Chrome and platinum) and has also worked on epithermal gold mines. He has worked on several European and international research projects and since 2011 has held the position of Head of the Mineral Deposit and Geophysics Research Unit at LNEG. During that time he has been called upon to represent LNEG in several European fora and has been an invited expert of a variety of raw material related matters at the request of the European Union.

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