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Executive Summary

This report was realized in the frame of the GSEU - Geological Service for Europe project by the team dedicated to raw materials. It presents a new evaluation of the European onshore critical raw materials (CRM) resources. It covers European countries, geographically speaking, including Albania, Austria, Belgium, Bosnia & Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark (including Greenland), Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Kosovo[1], North Macedonia, Montenegro, The Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine and the United Kingdom. It covers all critical raw materials of the 2023 list of the European Commission, except helium and silicon metal. Light and Heavy rare earth elements, that are distinguished in the 2023 CRM list of the European Commission have been treated as a single group of elements. Similarly, phosphate rock and phosphorus have been treated as a single commodity.

The first part of the report presents a knowledge-based assessment of the main CRM deposits in Europe, based on a thorough data collection and validation process involving individual Geological Survey Organisations within the GSEU consortium. Each of the 30 CRM in scope is covered in a different subsection, each containing two tables and a commodity map showing the location and mining activity status of the deposits. In the first table of each subsection, known deposits are listed in reverse order according to their size. Data includes known or estimated tonnages of resources/reserves, cumulative mined production and total endowment, mining activity status of the deposit and commodities presently extracted, and deposit class. In the second table, the known resources and reserves tonnages are evaluated based on classification standards, and aggregated per country.

The second part presents a data-driven predictive assessment of selected critical raw materials at continental scale – in the form of prospectivity maps – in order to identify high potential mineral provinces in Europe. A supervised machine learning method, combining a novel approach of data aggregation and Random Forest artificial intelligence algorithms, has been used to produce the prospectivity maps. The 11 commodities that have been studied are cobalt, copper, lithium, niobium, nickel, magnesium, manganese, antimony, tantalum, vanadium and tungsten. In addition to the maps, the performance of the 11 prospectivity models has been assessed with commonly used metrics and compared to previous studies.

The last part is an analysis of the current situation in Europe and relates to data reporting, collection, standardization and harmonisation, and to the limitations that result in terms of data quality and coverage. Secondary sources of critical raw materials, such as mining and processing waste, have not been covered in this report due to their characterization and assessment still being in progress.

[1] This designation (of Kosovo) is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

Abbreviations	
AUC	Area Under Curve
CBA	Cell Based Association
CRM	Critical Raw Materials
DBA	Disc Based Association
EC	European Commission
EGDI	European Geological Data Infrastructure
EU	European Union
GIS	Geographic Information System
GSOs	Geological Survey Organisations
H2020	Horizon 2020
MPM	Mineral Prospectivity Mapping
PGM	Platinum Group Metals
REE	Rare Earth Elements
RF	Random Forest
ROC	Receiver Operating Characteristic
WP	Work Package

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1. Introduction

Over the past fifteen years, Europe has made significant strides toward creating a harmonised, pan-European mineral resources database, through collaborations between GSOs and funded by successive EU framework programs (see Wittenberg et al., 2022 for a review of past EU projects). Among them, the ProMine project laid the groundwork by developing the first databases for primary and secondary mineral resources, described with common data models and lexicons. The ProMine MD database allowed the production of the first maps of Critical Raw Materials deposits in Europe (Bertrand et al., 2016), based on the first lists of CRM issued by the European Commission (2011, 2014, 2017). However, ProMine's static structure limited its long-term functionality, as it lacked provisions for regular updates after project completion. To address this, the Minerals4EU project developed a harvesting system linked to an IT platform (the European Geological Data Infrastructure, EGDI) that could query web services set up by national data providers (i.e. GSOs) to collect their data in a common INSPIRE format. Successive projects expanded upon this framework, including GeoERA-FRAME, which developed prospectivity and metallogenic maps to highlight mineral potential for critical raw materials across Europe. However, each project typically built its own database without enduring funding, resulting in multiple, disparate datasets that lack integration and coherence for end-users. This has led to the development under GeoERA-Mintell4EU of the unified, centrally managed MIN4EU database within EGDI. While this infrastructure is in place within EGDI, many data-providing GSOs still face technical and organisational hurdles. Past projects often relied on third-party GSOs for their pan-European data compilation, sometimes without full involvement from partner countries. Since 2022, a larger network of GSOs is actively engaged within the GSEU project to provide and harmonise mineral resources data across Europe. For the first time, all partners are taking an active role, allowing for greater scrutiny of both the data and the underlying practices. This collaborative approach is key to establish common practices and bridge knowledge gaps.

This report was realized in the frame of GSEU by the team dedicated to EU onshore CRM resources of the raw materials thematic domain. More specifically, the objective of this work is to evaluate the European primary CRM potential, to produce pan-European maps of mineral potential and prospectivity assessments. It is based on a database of European CRM that was carefully updated and verified by all GSEU data providers (national and regional geological survey organizations). This thorough data collection and update process allowed to produce a state-of-the-art of geological information on primary European CRM, identifying data gaps and bottlenecks.

This report presents an assessment of the domestic potential of Europe to supply critical raw materials. It covers the land areas of the following countries: Albania, Austria, Belgium, Bosnia & Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark (including Greenland), Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Kosovo[2], North Macedonia, Montenegro, The Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine and the United Kingdom. Note with the exception of Greenland, overseas departments and territories were excluded from the geographical scope of this report, which focuses on continental Europe and nearby islands.

A total of 30 raw materials from the EU critical list (European Commission, 2023) were evaluated (Table 1). Due to chemical affinities, some metals tend to occur in similar geological settings and are therefore discussed together in this report. Phosphate rock and phosphorus are sourced from the same deposit

[2] This designation (of Kosovo) is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

types. The latter is derived from processing the former, so these two CRM are discussed together. Rare earth elements (REE), including both the heavy and light rare earth elements (HREE & LREE), commonly occur together in mineral deposits and were thus discussed together, even though a distinction is made in the EU critical list (European Commission, 2023). Helium (traditionally sourced from the processing of natural gas) and silicon metal (produced from high purity quartz) resources in Europe were not addressed in this assessment due to the lack of data available.

Table 1: *The EU 2023 list of critical raw materials, including strategic raw materials in italic.*

	Critical raw material list (2023)	Commodity assessed in this report	Favourability map in this report
Aluminium/bauxite	X	X	
Antimony	X	X	X
Arsenic	X	X	
Baryte	X	X	
Beryllium	X	X	
Bismuth	X	X	
Boron/borate	X	X	
Cobalt	X	X	X
Coking coal	X	X	
Feldspar	X	X	
Fluorspar	X	X	
Gallium	X	X	
Germanium	X	X	
Hafnium	X	X	
Helium	X		
Lithium	X	X	X
Heavy Rare Earth Elements	X	Assessed together	
Light Rare Earth Elements	X		
Magnesium	X	X	X
Manganese	X	X	X
Natural graphite	X	X	
Niobium	X	X	X
Platinum Group Metals	X	X	
Phosphate rock	X	Assessed together	
Phosphorus	X		
Scandium	X	X	
Silicon metal	X		
Strontium	X	X	
Tantalum	X	X	X
Titanium metal	X	X	
Tungsten	X	X	X
Vanadium	X	X	X
Copper	X	X	X
Nickel	X	X	X

The bulk of this report is presented in two parts. The first part (sections 2 and 3) presents a knowledge-based assessment of the main CRM deposits in Europe, based on a thorough data collection and validation process involving individual Geological Survey Organisations (GSOs) within the GSEU consortium. The second part (section 4) presents a data-driven predictive assessment of 11 CRM at continental scale in the form of prospectivity maps (Table 1), in order to identify high potential mineral provinces. Section 5 is an analysis of the current situation in Europe concerning data reporting, collection, standardization and harmonisation, and the limitations that result in terms of data quality and coverage. Finally, secondary sources of CRM have not been covered in this report due to the characterization and assessment of mining waste still being in its infancy. More information is available in section 6 of this report. This topic will be addressed in detail in a future report (deliverable D2.6).

1.1. Terminology and Definitions

Some terms essential to the proper understanding of this report are briefly described below. The definitions follow their use by the minerals industry and the resource assessment community.

Mineral occurrence
A concentration of any useful mineral found in bedrock in sufficient quantity to warrant further exploration.

Mineral deposit
A mineral occurrence of sufficient size and grade that it might, under the most favourable circumstances, be considered to have economic potential.

Mineral resource
Resources whose location, grade, quality, and quantity are known or can be estimated from specific geological evidence.

Mineral reserve
Portion of a mineral resource that can be realistically and economically mined.

Figure 1 schematically illustrates the concepts of mineral resources and reserves of a given deposit. A resource is that amount of a mineral occurrence that exists in both identified and undiscovered deposits. The distinction between inferred, indicated and measured resources reflects an increasing degree of confidence in their occurrence, which is often correlated with the amount of exploration activities that have been carried out on that particular deposit (e.g. drilling). Reserves refer to that part of a resource, which have a known size, and can be exploited at a profit. At any given moment, part of the resources may be excluded from the reserves due to cost reasons (inaccessibility or difficult extraction, etc.) or quality (low grade, presence of a penalizing mineral, etc.). However, this situation can evolve with economic factors such as rising commodity market value, technological advances (new exploitation or processing methods), or an administrative change such as a land acquisition that provides access to these resources.

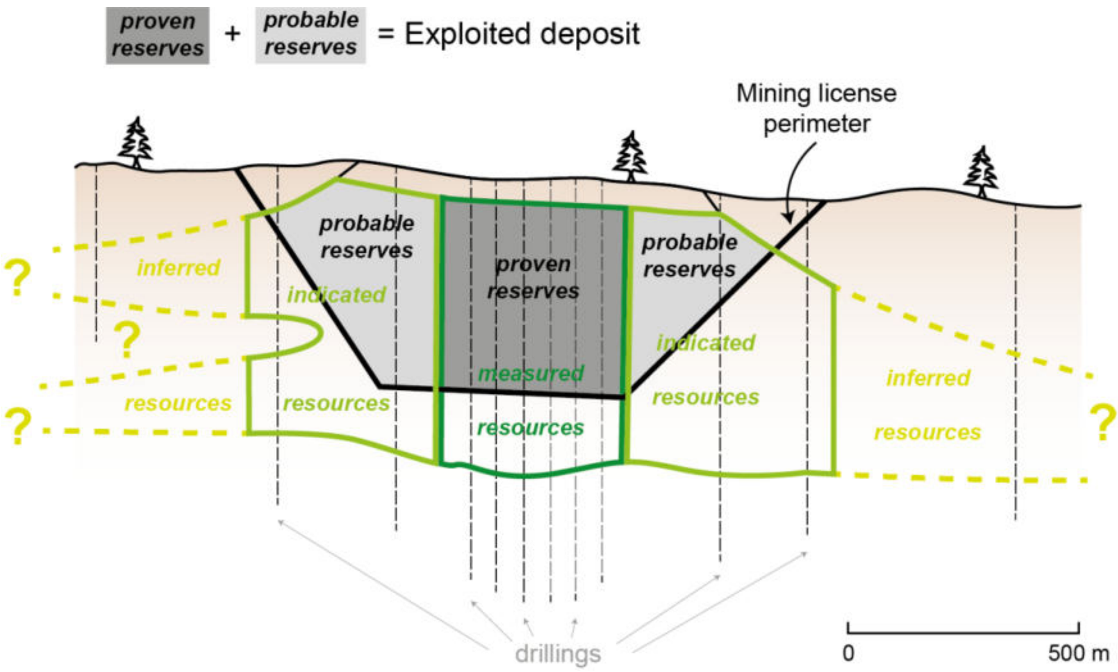


Figure 1: *Figure illustrating the notions of resources and reserves of a potential deposit. The degree of knowledge of resources and reserves is directly correlated with the amount of drilling and other exploration activities. As is the case for a majority of deposits, a large part of resources will never become reserves, and will never be exploited. Figure from Marcoux (2023).*

1.2. Deposit Size

To compare the mineral potential of deposits across borders, several attempts to classify their magnitude categories have been made (Laznicka, 2010). Since the early 2010s, Europe has adopted a classification system based on the total endowment – estimated by the sum of cumulated production, reserves and resources – in which mineral deposits have been discriminated in five size classes (A: super large, B: large, C: medium, D: small, E: showing) of commodity contained (European Commission, 2013). This classification system was first coined in the late 1990s at the French Geological Survey for the needs of global metallogenic syntheses (Milési and Deschamps, 2001), and was reviewed in the late 2000s by an international experts panel. For each commodity, these classes were defined by calibration on known deposits and refined after statistical examination of the distribution of the different classes. This classification method ignores the prevailing economic conditions, which are extremely variable, and differs from classifications based on annual production rates (of ore or commodity tonnage), subject to market influences. Importantly, it also considers mined deposits, past or present, where all or part of the commodity has been extracted. In other words, a large deposit does not necessarily correspond to a large active mine and vice versa. The lexicon "ImportanceValue" (European Commission, 2013; Cassard et al., 2015) thus fixes, for each substance, the limits of these classes. In the case of a deposit composed of several commodities, several size classes can be, and are, calculated. Table 2 presents the class boundaries used for the selected CRM. This report only considers the largest sized mineral deposits (super large (class A), large (class B) and medium (class C)).

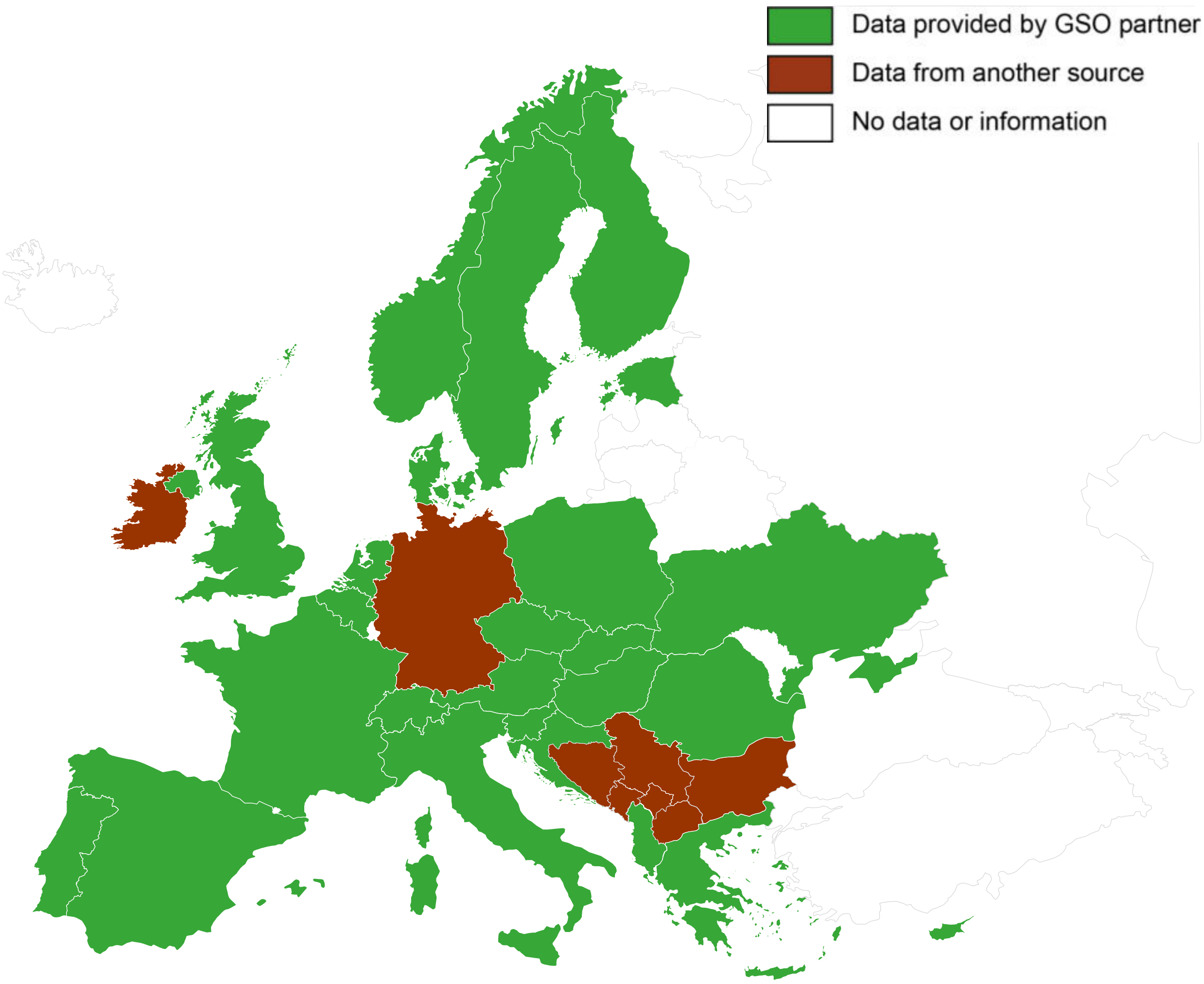
Table 2: *Minimum class threshold values for CRM commodities, in tons of commodity (reported in the second column).*

CRM	Commodity reported	Super large deposits (class A)	Large deposits (class B)	Medium deposits (class C)	Small deposits (class D)
Aluminium/bauxite	Al_2O_3	1 000 000 000	100 000 000	10 000 000	1 000 000
Arsenic	As (metal)	200 000	20 000	2 000	200
Boron/borate	B_2O_3	25 000 000	2 000 000	100 000	10 000
Baryte	$BaSO_4$	5 000 000	1 000 000	200 000	50 000
Beryllium	BeO	20 000	2 000	200	50
Bismuth	Bi (metal)	20 000	2 000	200	2
Cobalt	Co (metal)	500 000	50 000	2 000	200
Coking coal	Coking coal	10 000 000 000	1 000 000 000	100 000 000	5 000 000
Copper	Cu (metal)	10 000 000	1 000 000	100 000	10 000
Feldspar	Feldspar	100 000 000	10 000 000	1 000 000	100 000
Fluorspar	CaF_2	5 000 000	1 000 000	200 000	50 000
Gallium	Ga (metal)	100	50	10	1
Germanium	Ge (metal)	500	100	20	5
Graphite	Graphite	10 000 000	1 000 000	100 000	10 000
Hafnium	Hf (metal)	10 000	1 000	100	10
Lithium	Li_2O	1 000 000	100 000	50 000	5 000
Magnesium	$MgCO_3$	100 000 000	10 000 000	1 000 000	100 000
Manganese	Mn (metal)	100 000 000	10 000 000	1 000 000	100 000
Niobium	Nb_2O_5	1 000 000	100 000	10 000	2 000
Nickel	Ni (metal)	2 000 000	500 000	20 000	2 000
Platinum Group Metals	PGM (metal)	1 000	100	10	1
Phosphorus/phosphate rock	P_2O_5	200 000 000	20 000 000	2 000 000	200 000
Rare Earth Elements	RE_2O_3	1 000 000	100 000	10 000	1 000
Antimony	Sb (metal)	100 000	25 000	2 000	1 000
Scandium	Sc (metal)	1 000	100	10	1
Silicon metal	SiO_2	10 000 000	1 000 000	100 000	10 000
Strontium	$SrCO_3$ or $SrSO_4$	1 000 000	100 000	10 000	1 000
Tantalum	Ta_2O_5	25 000	2 000	1 000	200
Titanium metal	TiO_2	20 000 000	2 000 000	200 000	20 000
Titanium metal	Ilmenite	20 000 000	2 000 000	200 000	20 000
Titanium metal	Rutile	2 000 000	200 000	20 000	2 000
Vanadium	V (metal)	2 000 000	200 000	20 000	2 000
Tungsten	WO_3	200 000	50 000	5 000	500

2. Mineral Resource Data in Europe

2.1. Data Compilation

Data compilation for this report was largely based on contributions from national and regional Geological Survey Organisations. Where data was available to them, deposit information was entered in an Excel spreadsheet. Completion and validation of the inventory, i.e. ensuring that all data is described in a consistent way, and that the level of knowledge and representation is similar throughout Europe, was undertaken by the task leader, in the majority of cases with the partner's validation. This inventory brought useful data on tonnage of remaining and extracted amount of CRM, and the presence of mining activity. The geographic coverage however was not exhaustive (Figure 2), either because some GSOs are not partners in task 2.1 of GSEU dedicated to EU onshore CRM resources, or because some GSOs partners did not contribute data. To produce full European coverage, data for some countries was sourced from the ProMine Mineral Deposit database (Bosnia & Herzegovina, Bulgaria, Ireland, Kosovo[3], Montenegro, North Macedonia). For those countries, the information provided in this report is qualitative rather than quantitative, and no tonnage data is provided. For Germany and Serbia, tonnage data was mostly recovered from public sources.



[3] This designation (of Kosovo) is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

More specifically, GSOs were requested to provide the following information for each deposit:

- Name
- Commodity (one entry per commodity. Deposits composed of several commodities require several entries)
- Coordinates (latitude and longitude, in WGS84 format)
- Deposit size (lexicon guided, calculated based on the tonnage threshold values in Table 2)
- Deposit type
- Resources
  - Commodity tonnage + type of commodity reported
  - Commodity grade and unit
  - Resource category (lexicon guided; see Annex Table 74)
  - Resource classification method (lexicon guided; see Annex Table 75)
- Reserves
  - Commodity tonnage + type of commodity reported
  - Commodity grade and unit
  - Reserve category (lexicon guided; see Annex Table 76)
  - Reserve classification method (lexicon guided; see Annex Table 75)
- Mined production (cumulative)
  - Commodity tonnage + type of commodity reported
  - Commodity grade and unit
- Mine status for the deposit (lexicon guided; see Annex Table 77)

2.2. Data Processing and Content Overview

To ensure interoperability, data processing and attribute harmonisation was required. The process was the following:

Figure 2: *Map of Europe showing the source of data and information collected for this report.*

1) **Identify and remove duplicates**

2) **Harmonise attributes "type of commodity reported"**
For some commodities, tonnages can be expressed in different ways. For example, phosphate rock/phosphorous can be expressed in tons of phosphorus pentoxide (P_2O_5) or tons of elemental phosphorus (P). Some conversions were necessary to ensure data comparability, including comparability to the deposit size threshold values in Table 2.

3) **Calculate total endowment**
The total endowment of a deposit is the sum of its resources, reserves (if not already counted as part of the resources) and cumulative extracted tonnage of commodity.

4) **Verify (and correct if necessary) deposit size**
The size of a deposit for a given commodity is defined according to the threshold values provided in Table 2.

5) **Group deposit status into five categories:**

- ***Active extraction***

Includes the attributes “operating”, “operatingContinuously” and “operatingIntermittently”.

- ***Active project***

Includes the attributes “feasibility”, “pendingApproval”, “underDevelopment” and “construction”. This category includes advanced active projects with a significant amount of drilling, a resource estimate, or any stage of economic study, construction, or pending approval.

- ***Past extraction***

Includes the attributes “abandoned”, “careAndMaintenance”, “closed”, “historic” and “notOperating”. This category includes historic mines (i.e. pre-1900s) as well as more recent exploitations where mining activity has ceased, with or without potential to resume operations at a later date.

- ***Unexploited***

This category was not lexicon guided, but some data providers wished to indicate deposits which are not currently exploited.

- ***Not specified***

No information received.

6) **Categorise remaining commodity** (resources and reserves) based on reporting classification standards:

- ***Mineral reserves***

Available for extraction (licensing allowing). Includes the following:

  - Proven and probable reserves (CRIRSCO-compliant classification systems, e.g. JORC, NI 43-101, PERC, CIM)
  - Approved mineral reserves of the A, B, C_1 and C_2 categories (Russian NAEN code)
  - UNFC 111 and 112

- ***Mineral resources***

In development for extraction. Includes the following:

  - Measured, indicated and inferred resources (CRIRSCO-compliant classification systems, e.g. JORC, NI 43-101, PERC, CIM)
  - Not-approved mineral resources of the A, B, C_1, C_2 and D categories (Russian NAEN code)
  - UNFC 221, 222 and 223

- ***Compliant historic estimates***

Previously estimated resources, which require revisions and adaptations to ensure feasibility. Includes the following:

  - Prospected resources of the P1 and P2 categories (Russian NAEN code)
  - UNFC 331, 332 and 333
  - Historic resource estimates compliant with national or international reporting standards

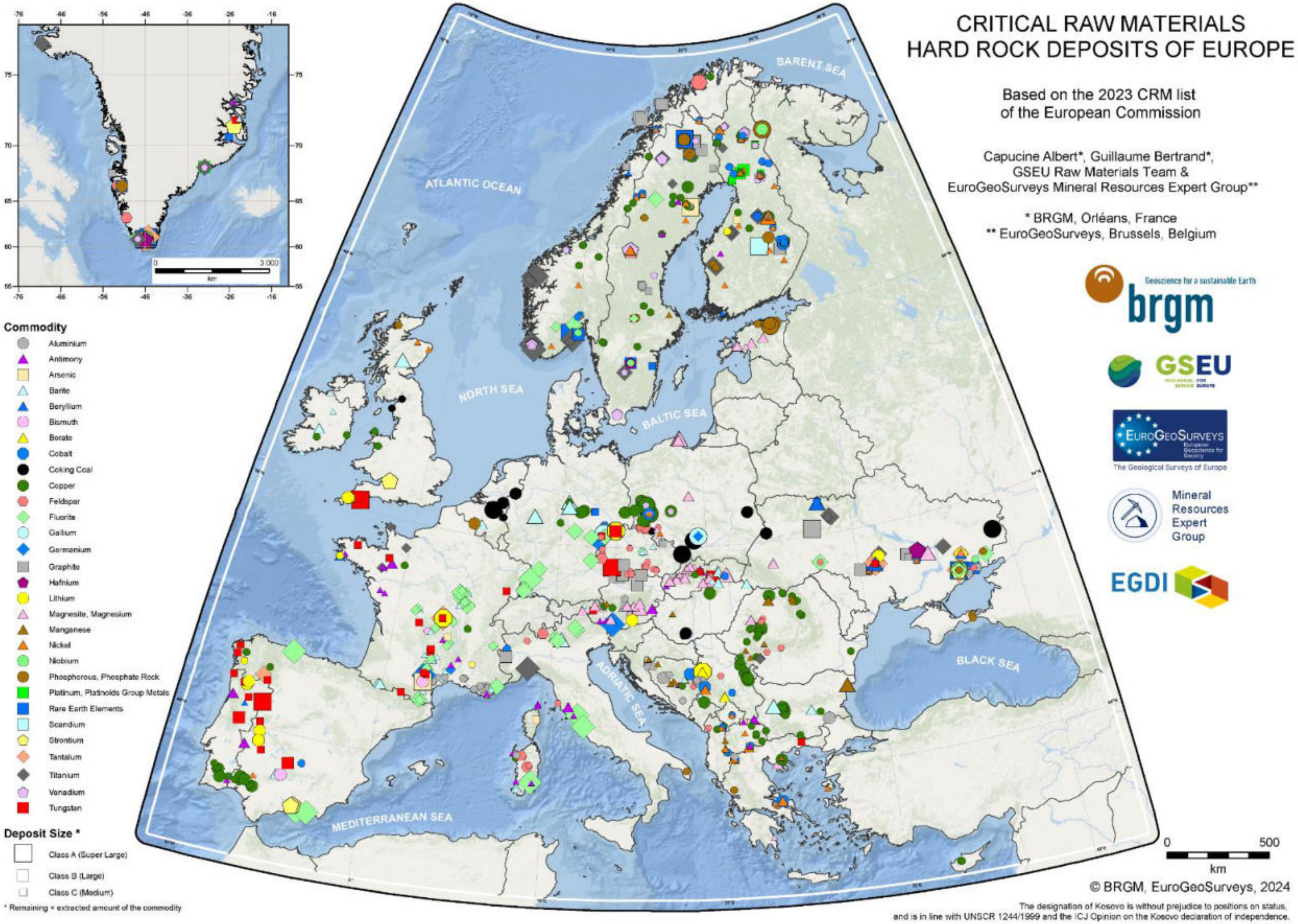
- ***Historical or non-compliant resource estimates***

Early exploration phase, not currently explored as target commodity, or resources non-compliant with reporting standards. Includes the following:

- Historic estimates
- Non-compliant resource estimates
- Explored resources
- Poorly documented resources
- UNFC 334

The final dataset contains 842 CRM deposits across 30 European countries. They are displayed in Figure 3. For 75% of these deposits, reasonably documented information exists on tonnages of resources/reserves and/or cumulative production. Although we aimed to compile information as thoroughly as possible, some fields remain blank for several reasons: no information available (7%), confidential information (18%) or highly doubtful information. In cases where tonnage data was not available, we derived an estimate of the total tonnage endowment for each deposit, by assuming the lower threshold of its size category from Table 2. This approximation thus only provides a minimum total tonnage estimate. This concerns the following: Austria (24), Czech Republic (41), Slovakia (36), Ukraine (16), Romania (31), Italy (5), Bosnia & Herzegovina (22), Bulgaria (14), Ireland (7), North Macedonia (12), Montenegro (1) and Serbia (1). In those cases, it is not known what amount of that tonnage has already been extracted, if any.

Figure 3: *Map of hard rock primary CRM deposits in Europe of 2024. The map contains 842 deposits of former or current economic character. The size of the symbol indicates the size class of the deposit for that commodity.*



3. Individual CRM Potential Assessments

In this section we describe the largest CRM deposits in Europe. Each CRM is covered in a different subsection, each containing two tables and a commodity map showing the location and mining activity status of the deposits.

In the **first table** of each subsection, known deposits are listed in reverse order according to their size. Data includes known or estimated tonnages of resources/reserves, cumulative mined production and total endowment, mining activity status of the deposit and commodities presently extracted, and deposit class. Resources/reserves can refer to both mineral resources according to the current industry standards (as required by stock exchanges) or resources not according to such standards; the latter are often called 'historic' or 'non-compliant' resources.

In the **second table**, the known resources and reserves tonnages are evaluated based on reporting classification standards, and aggregated per country. Note that resources/reserves from confidential projects are not accounted for. Each category corresponds to a level of confidence in the estimation:

- **Category 1 – Mineral reserves** – Available for extraction (licensing allowing)
- **Category 2 – Mineral resources** – In development for extraction
- **Category 3 – Compliant historical estimates** – Previously estimated resources, which require revisions and adaptations to ensure feasibility
- **Category 4 – Other historical or non-compliant resource estimates** – Early exploration phase, not currently explored as target commodity, or resources non-compliant with reporting standards.

Note that as explained in the introduction, the CRM helium and silicon metal were not evaluated. Note also that GSOs in Croatia, Slovenia and Switzerland reported that the countries do not host significant CRM deposits.

Finally, the presence of a mineralization and the identification of a mineral resource do not warrant its extractability in the future. This report constitutes a geological assessment of the main CRM deposits in Europe, and it does not consider any aspect associated with infrastructure, mining, metallurgy, processing, transport of ore or the like, and ignores economic and environmental conditions.

3.1. Aluminium/Bauxite (Al_2O_3)

Aluminium does not occur as pure metal in nature, it is recovered from refining and smelting of bauxite ore. European bauxite deposits are typically associated with karstic deposits (e.g. in Greece, the Balkans, Hungary, and France where historically significant deposits are located), and with lateritic deposits (e.g. in some regions of Italy).

***Table 3:** Main European aluminium/bauxite deposits identified in 2024. Tonnages are in tons of Al_2O_3.*

Name	Country	Class	Deposit status	Commodi-ties currently mined	Confi-dential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
District de Brignoles	France	B	Historic		no	118500000		16757000	135257000
Sarnitsa	Bulgaria	B							100000000[m]
Gradina (Baraci)	Bosnia & Herzegovina	B							100000000[m]
Bracan (Milici)	Bosnia & Herzegovina	B							100000000[m]
Crvene stijene (Milici)	Bosnia & Herzegovina	B							100000000[m]
Kosturi (Srebrenica)	Bosnia & Herzegovina	B							100000000[m]
Les Baux (Canonnettes-Manville)	France	C	Historic		no	72940000		2000000	74940000
Ollières	France	C			no	60000000			60000000
District de Villeveyrac	France	C	Operating	Bauxite	no	53830000		4977000	58807000
Olmedo	Italy	C	Closed		no	31000000	3000000	3720000	34720000
Allauch	France	C	Historic		no	30000000		297000	30297000
Vrontero	Greece	C	Not oper-ating		no	24000000			24000000
Mazaugues	France	C	Historic		no	13250000		8790000	22040000
L'Arboussas	France	C	Operating	Bauxite	no	15000000		5940328	20940328
Parisot	France	C	Historic		no	18990000		50000	19040000
Doze-Gagère	France	C	Historic		no	10500000		8500000	19000000
Mas Rouge	France	C	Historic		no	14350000		72000	14422000
Le travers des Romarins	France	C	Closed		no	12000000		186126	12186126
Pierrerue	France	C			no	12000000			12000000
Creissan Quarante	France	C	Historic		no	10000000		31434	10031434
Prefingkogel	Austria	C	Aban-doned		yes				10000000[m]
Jasenica-Lusci Palanka	Bosnia & Herzegovina	C							10000000[m]
Bosanska Krupa	Bosnia & Herzegovina	C							10000000[m]
Vlasenica	Bosnia & Herzegovina	C							10000000[m]
Mostar district	Bosnia & Herzegovina	C							10000000[m]
Jajce	Bosnia & Herzegovina	C							10000000[m]

[m] minimum estimate

***Table 4:** Aluminium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – aluminium contained (tons of Al_2O_3)	Category
France	**441360000**	4 – historical or non-compliant
Greece	**24000000**	4 – historical or non-compliant
Italy	**3000000** **28000000**	1 – mineral reserves 4 – historical or non-compliant

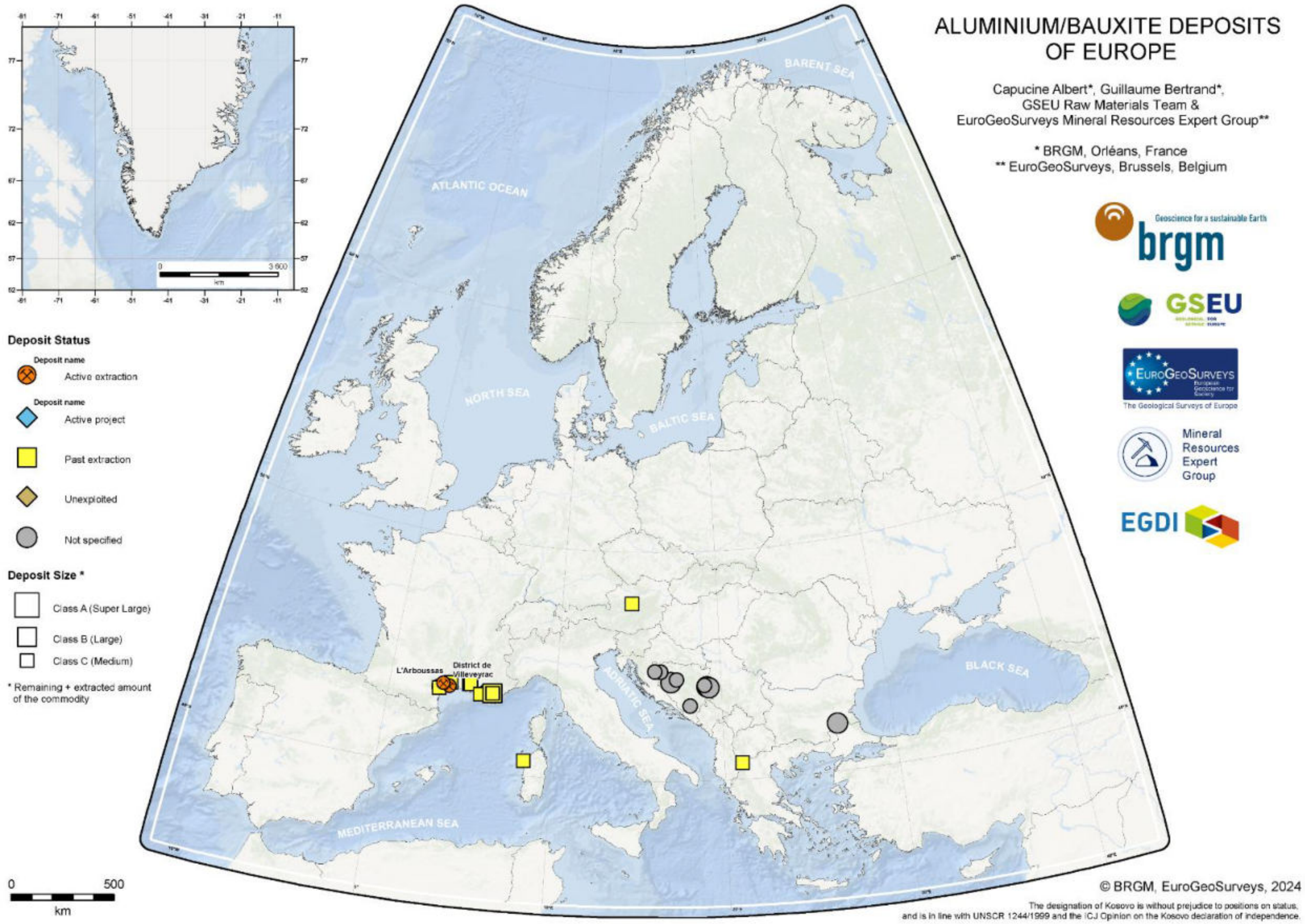


Figure 4: *Map of aluminium/bauxite deposits in Europe.*

3.2. Antimony (Sb)

Antimony can be sourced as a main product (the main commercial source of antimony is stibnite (Sb_2S_3)), as a by-product from gold and silver ore extraction, and as by-product from the smelting process of zinc and lead.

***Table 5:** Main European antimony deposits identified in 2024. Tonnages are in tons of Sb metal.*

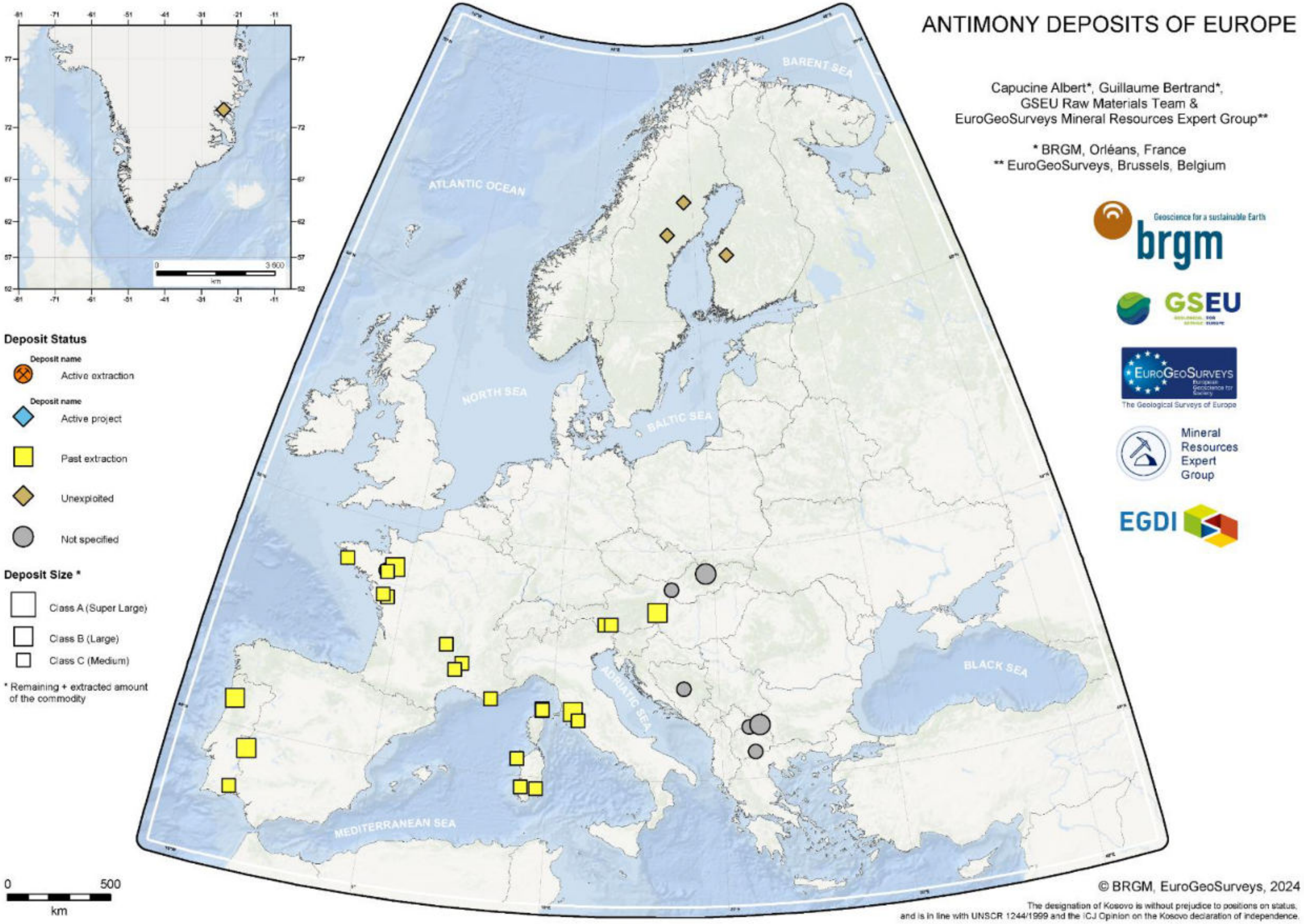
Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
San Antonio	Spain	B	Not operating		no	70000			70000
La Lucette	France	B	Historic		no			42000	42000
Ribeiro da Serra, Lugar da Fontinha e Tapada	Portugal	B	Abandoned		no	14400		12841	27241
Schlaining-Kurtrevier	Austria	B	Abandoned		yes				25000[m]
Pietratonda	Italy	B	Abandoned		yes				25000[m]
Krstov Dol	North Mace-donia	B							25000[m]
Dúbrava	Slovakia	B			yes				25000[m]
Ingurtosu	Italy	C	Closed		no	320		24000	24320
District de Brioude-Massiac	France	C	Historic		no	500		21500	22000
Le Semnon	France	C	Historic		no	19500		500	20000
Tafone	Italy	C	Abandoned		no	17500			17500
Rochetréjoux	France	C	Historic		no	100		16500	16600
La Coëfferie	France	C			no	14355			14355
Les Touches	France	C			no	11494			11494
Rakkejaur	Sweden	C	Not exploited		no	10200			10200
Les Brouzils	France	C	Historic		no	9250		895	10145
Rockliden	Sweden	C	Not exploited		no	6700			6700
Méria	France	C	Historic		no	400		5600	6000
Luri	France	C	Historic		no	2000		3400	5400
Valcros	France	C	Historic		no	4300		200	4500
Margeries Dal North	Greenland	C	Not exploited		no	3780			3780
Ty Gardien	France	C	Historic		no	2785		565	3350
Su Suergiu	Italy	C	Closed		no	216		3000	3216
Largentière	France	C	Historic		no			3000	3000
Argentiera della Nurra	Italy	C	Abandoned		no			3000	3000
Cortes Pereiras	Portugal	C	Abandoned		no	2450		115	2565
Kalliosalo	Finland	C	Not exploited		no	2550			2550
Saint-Michel de Dèze	France	C	Historic		no			2500	2500
Ersa	France	C	Historic		no			2000	2000
Rabant	Austria	C	Abandoned		yes				2000[m]
Lessnig-Obergottesfeld	Austria	C	Abandoned		yes				2000[m]
Cemernica	Bosnia & Herzegovina	C							2000[m]
Lojane	North Mace-donia	C							2000[m]
Alsar	North Mace-donia	C							2000[m]
Pezinok	Slovakia	C			yes				2000[m]

[m] minimum estimate

Table 6: *Antimony resources/reserves from the main deposits in Europe.*

Country	Remaining resources – antimony contained (tons of Sb metal)	Category
Finland	**2550**	4 – historical or non-compliant
France	**64684**	4 – historical or non-compliant
Greenland	**3780**	4 – historical or non-compliant
Italy	**18036**	4 – historical or non-compliant
Portugal	**16850**	4 – historical or non-compliant
Spain	**70000**	4 – historical or non-compliant
Sweden	**6700** **10200**	2 – mineral resources 4 – historical or non-compliant

Figure 5: Map of antimony deposits in Europe.



3.3. Arsenic (As)

Arsenic is primarily obtained as a by-product during smelting of ores for other metals including copper, lead and gold. Historically, some arsenic-rich ores (e.g. arsenopyrite) were mined directly for their arsenic content, but this practice has largely diminished due to environmental and health concerns.

Table 7: *Main European arsenic deposits identified in 2024. Tonnages are in tons of As metal.*

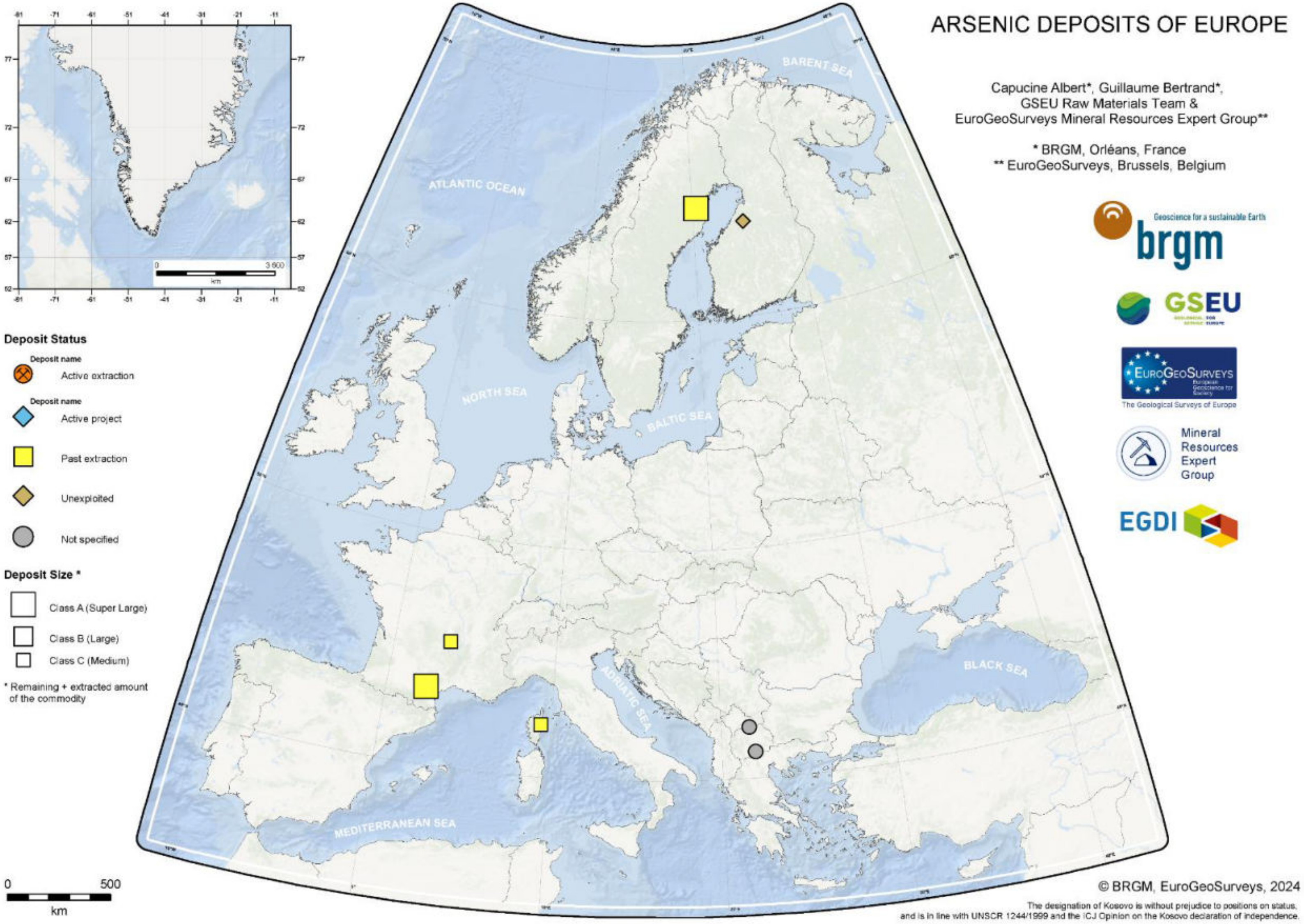
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Boliden	Sweden	A	Closed		no			571200	571200
Salsigne	France	A	Closed		no			300000	300000
Matra	France	C	Historic		no			8000	8000
Rodier	France	C	Historic		no			3000	3000
Vesiperä	Finland	C	Not exploited		no	2400			2400
Lojane	North Macedonia	C							2000[m]
Alsar	North Macedonia	C							2000[m]

[m] minimum estimate

Table 8: *Arsenic resources/reserves from the main deposits in Europe.*

Country	Remaining resources – arsenic contained (tons of As metal)	Category
Finland	**2400**	4 – historical or non-compliant

Figure 6: *Map of arsenic deposits in Europe.*



3.4. Baryte (Natural Barium Sulphate, $BaSO_4$)

Baryte is a mineral composed of barium sulphate ($BaSO_4$), and often occurs alongside minerals such as fluorite, quartz, and sulphides of lead, zinc, and silver.

Table 9: *Main European baryte deposits identified in 2024. Tonnages are in tons of $BaSO_4$.*

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Marigole	Italy	A	Abandoned		no	12300000		10973313	23273313
Duntanlich	UK	A	Operating	Baryte	no	20000000			20000000
Meggen	Germany	A	Historic		no			8460000	8460000
Wolkenhügel	Germany	A	Historic		no			6000000	6000000
Rammelsberg	Germany	A	Historic		no			5940000	5940000
Kremikovtsi	Bulgaria	A							5000000[m]
Brunndöbra	Germany	B	Closed		no	2700000		900000	3600000
Laghetto di Polzone	Italy	B	Abandoned		no	2656800		714336	3371136
Arrens	France	B	Historic		no	3000000		2000	3002000
Chaillac (Rossignol)	France	B	Closed		no	0		2600000	2600000
Pierrefitte	France	B			no	2000000			2000000
Fleurus	Belgium	B	Closed		no			1600000	1600000
Barega	Italy	B	Closed		no	1000000		567642	1567642
Pessens	France	B	Historic		no	600000		900000	1500000
Courcelles-Frémoy	France	B	Historic		no	470000		777000	1247000
Silius	Italy	B	Under devel-opment		no	1000000		220000	1220000
Biganske	Ukraine	B	Not operating		no		1175000*		1175000
Guillermin	Spain	B	Not operating		no	311955		750000	1061955
Stara Zagora	Bulgaria	B							1000000[m]
Rudabánya	Hungary	B	Feasibility		yes				1000000[m]
Silvermines	Ireland	B							1000000[m]
Rudňany	Slovakia	B			yes				1000000[m]
Markušovce	Slovakia	B			yes				1000000[m]
Sa Corona 'e sa Craba-Barbusi	Italy	C	Closed		no	1000000			1000000
Les Porres	France	C	Historic		no	300000		680000	980000
Chessy les Mines	France	C	Closed		no	860000			860000
Lacan (Malacroux)	France	C	Historic		no	750000		60000	810000
Martlingerod	Germany	C	Historic		no			700000	700000
Les Farges	France	C	Historic		no	400000		217000	617000
Niederschlag	Germany	C	Operating	Fluorspar, baryte	no	560000			560000
Les Malines	France	C			no	500000			500000
Saint Geniez-d'Olt (Le Minier)	France	C	Historic		no	300000		140000	440000
Les Renauds	France	C			no	430000			430000
Mont Marcus-Hermita	France	C	Historic		no	170000		240000	410000
Montpestels	France	C	Historic		no	200000		120000	320000
Font d'Arques-Villeneu-vette	France	C	Historic		no			300000	300000
Oksedal	Greenland	C	Not exploited		no	264000			264000
Bredehorn, Zebra Klint	Greenland	C	Not exploited		no	216000			216000
Reither Kogl	Austria	C	Abandoned		yes				200000[m]
Veovaca	Bosnia & Herzegovina	C							200000[m]
Podkovac	Bosnia & Herzegovina	C							200000[m]

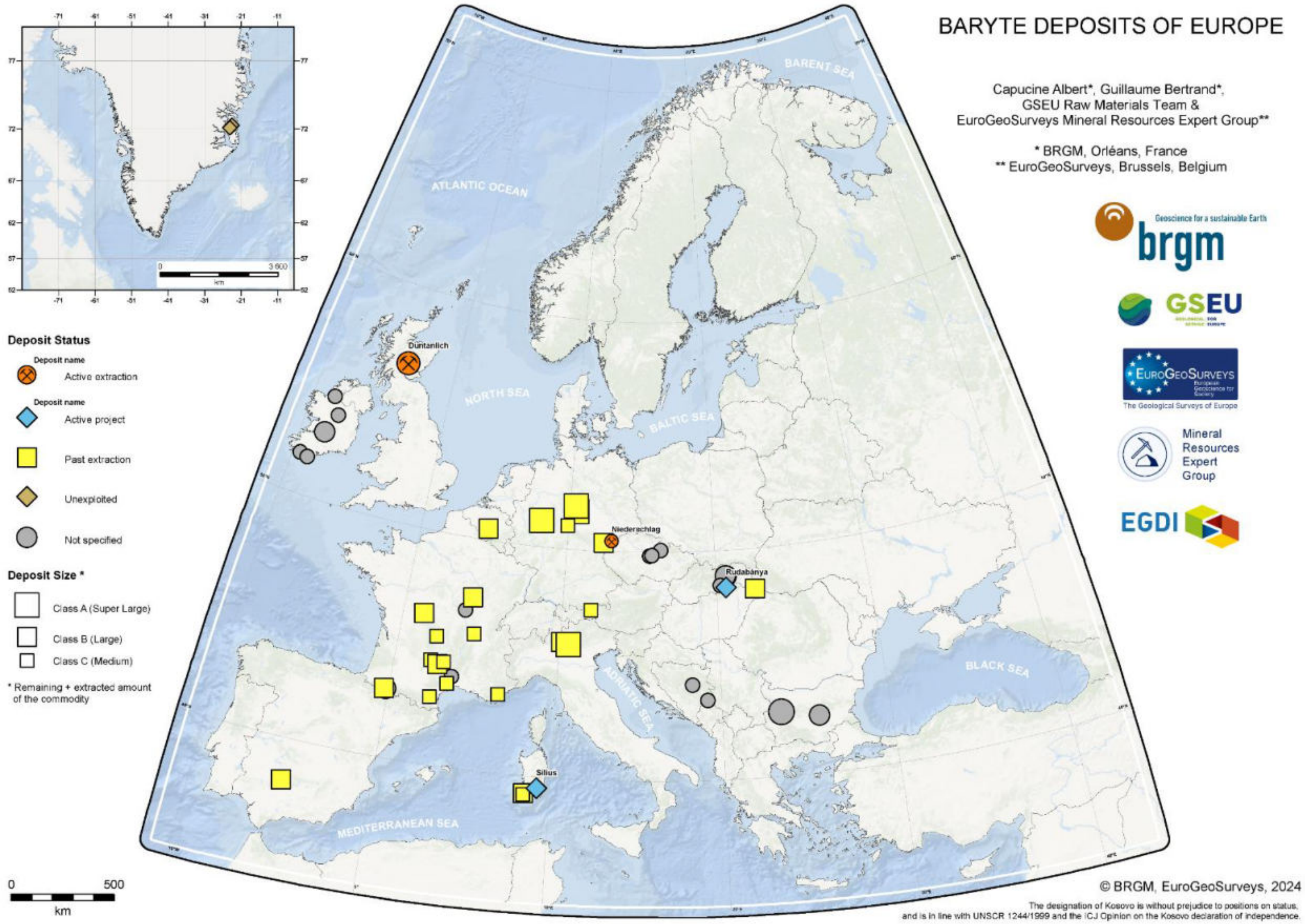
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Bestvina	Czechia	C			yes				200000[m]
Bohousova	Czechia	C			yes				200000[m]
Krizanovice	Czechia	C			yes				200000[m]
Garrycam	Ireland	C							200000[m]
Benbulben	Ireland	C							200000[m]
Derryginagh	Ireland	C							200000[m]
Lady's Well	Ireland	C							200000[m]
Gemerská Ves	Slovakia	C			yes				200000[m]

[m] minimum estimate
* reserves not included in resources

Table 10: *Baryte resources/reserves from the main deposits in Europe.*

Country	Remaining resources – baryte contained (tons of $BaSO_4$)	Category
France	**9980000**	4 – historical or non-compliant
Germany	**3260000**	4 – historical or non-compliant
Greenland	**480000**	4 – historical or non-compliant
Italy	**17956800**	4 – historical or non-compliant
Spain	**311955**	4 – historical or non-compliant
UK	**20000000**	4 – historical or non-compliant
Ukraine	**1175000**	1 – mineral reserves

Figure 7: *Map of baryte deposits in Europe.*



3.5. Beryllium (Be)

The two most used beryllium minerals are bertrandite ($Be_4Si_2O_7(OH)_2$), and beryl ($Be_3Al_2Si_6O_{18}$). Both minerals are most often found in veins or pegmatites associated with granitic rocks.

Table 11: *Main European beryllium deposits identified in 2024. Tonnages are in tons of BeO.*

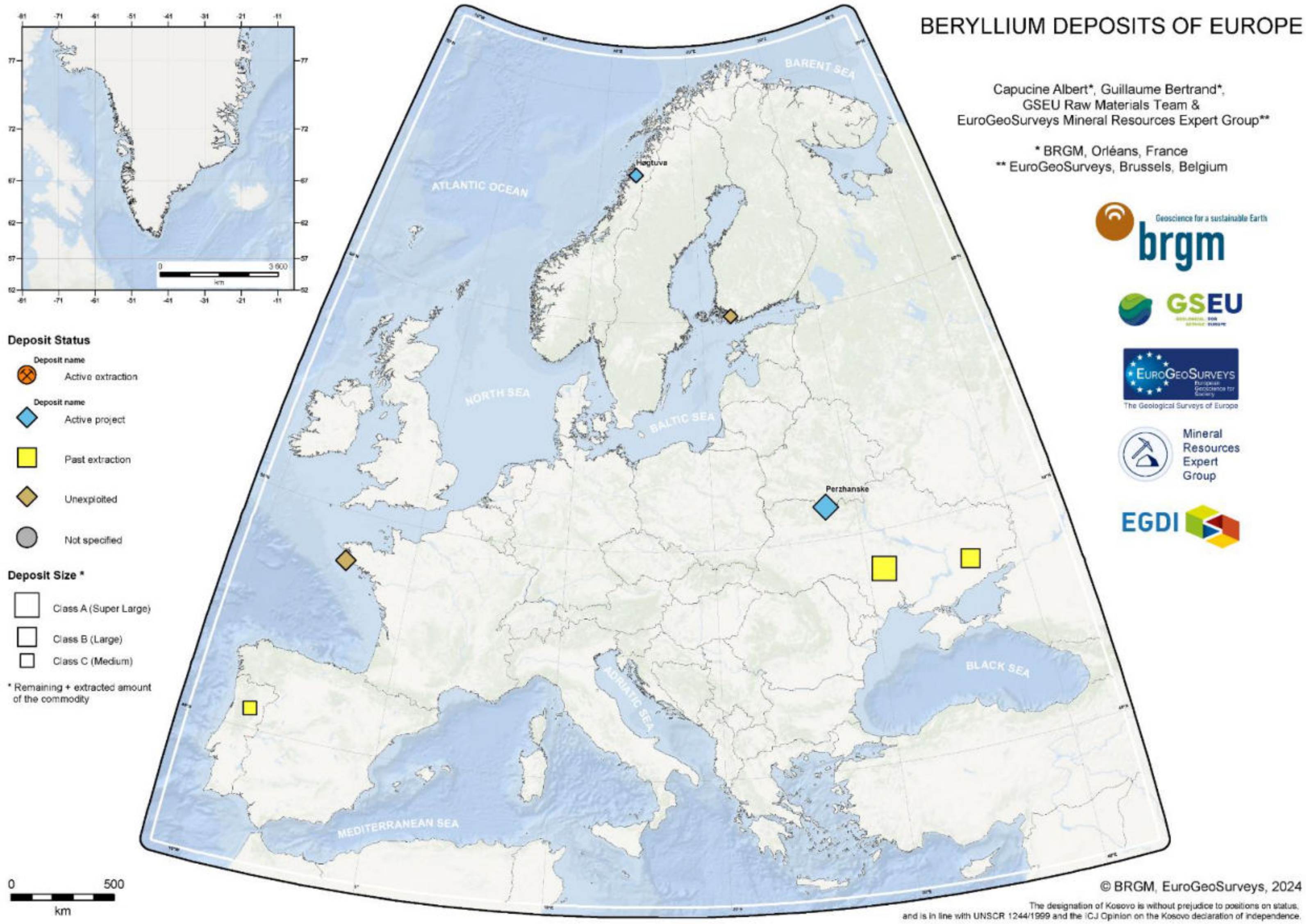
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Perzhanske	Ukraine	A	Feasibility		no		18565*	144730	163295
Dobra	Ukraine	A	Not operating		no	61290			61290
Shevchenkivske	Ukraine	B	Not operating		no	5674			5674
Tréguennec-Prat-ar-Hastel	France	B	Not exploited		no	2400			2400
Høgtuva	Norway	C	Feasibility		no	1749			1749
Carrasqueira	Portugal	C	Abandoned		no			992	992
Rosendal	Finland	C	Not exploited		no	510			510

* reserves not included in resources

Table 12: *Beryllium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – beryllium contained (tons of BeO)	Category
Finland	**510**	4 – historical or non-compliant
France	**2400**	4 – historical or non-compliant
Norway	**1749**	4 – historical or non-compliant
Ukraine	**18565** **66964**	1 – mineral reserves 2 – mineral resources

Figure 8: *Map of beryllium deposits in Europe.*



3.6. Bismuth (Bi)

Bismuth is often associated with other metals like lead, copper, gold, silver, tin and tungsten in polymetallic ores, where it is typically recovered as a by-product of the extraction of these metals.

Table 13: *Main European bismuth deposits identified in 2024. Tonnages are in tons of Bi metal.*

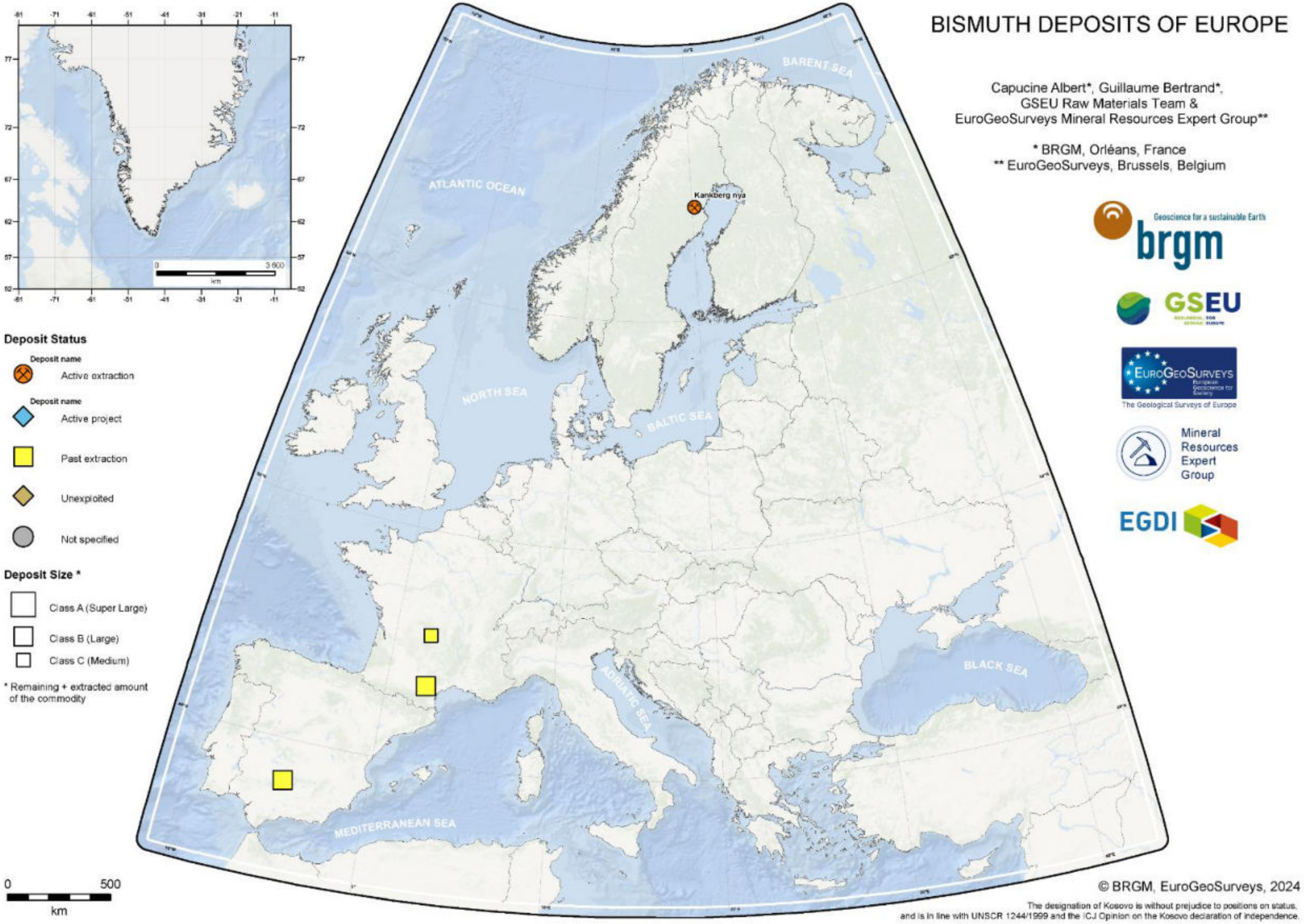
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
La Espuela de San Miguel	Spain	B	Abandoned		no	200		5000	5200
Salsigne	France	B	Closed		no	2527		2000	4527
Kankberg nya	Sweden	C	Operating	Au, Te	no	132	429*		562
La Grande	France	C	Historic		no			300	300

* reserves not included in resources

Table 14: *Bismuth resources/reserves from the main deposits in Europe.*

Country	Remaining resources – bismuth contained (tons of Bi metal)	Category
France	**2527**	4 – historical or non-compliant
Spain	**200**	4 – historical or non-compliant
Sweden	**429** **132**	1 – mineral reserves 2 – mineral resources

Figure 9: *Map of bismuth deposits in Europe.*



3.7. Boron/borate (B_2O_3)

Boron is primarily found in borate minerals such as borax, kernite and colemanite, which typically form in arid regions through the evaporation of saline lakes.

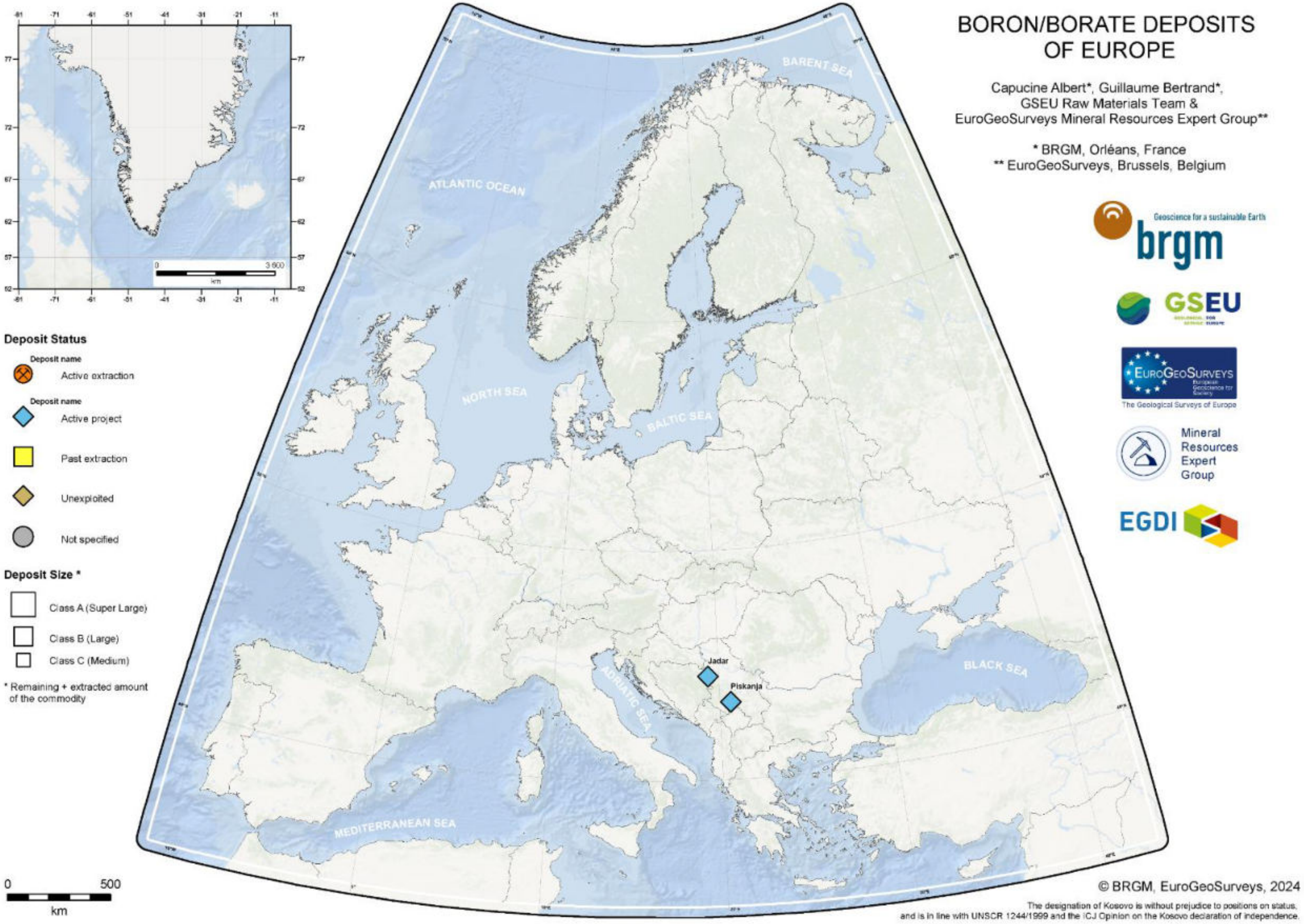
Table 15: *Main European boron/borate deposits identified in 2024. Tonnages are in tons of B_2O_3.*

Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Jadar	Serbia	B	Under development		no	22131292			22131292
Piskanja	Serbia	B	Under development		no	2473660			2473660

Table 16: *Boron/borate resources/reserves from the main deposits in Europe.*

Country	Remaining resources – boron contained (tons of B_2O_3)	Category
Serbia	**24604952**	2 – mineral resources

Figure 10: *Map of boron/borate deposits in Europe.*



3.8. Cobalt (Co)

Cobalt is found in economic concentrations in deposits of other metals (e.g. nickel, copper, iron) where it occurs mainly in Co-bearing minerals (e.g. pyrite, pentlandite) rather than strictly cobaltiferous minerals. Cobalt is a most often a by-product of nickel and copper mining.

Table 17: *Main European cobalt deposits identified in 2024. Tonnages are in tons of Co metal.*

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Mokra Gora	Serbia	B			no	360000			360000
Talvivaara	Finland	B	Operating	Ni, Co	no	177232	99788*	1189	278209
New Copper District	Poland	B	Operating	Cu, Ag, Pb, Ni, Re, Au	no	155120		1740	156860
Evia	Greece	B	Not operating		no	73000			73000
Outokumpu	Finland	B	Closed		no			54356	54356
Brezik-Tadici	Bosnia & Herzegovina	B							50000[m]
Hotinvaara	Finland	C	Not exploited		no	40012			40012
Guri Kuq	Albania	C	Operating	Ni	no	39975			39975
Kevitsa	Finland	C	Operating	Ni, Cu, Co, Pt, Pd, Au	no	20003	7389*	5707	33099
Hannukainen	Finland	C	Closed		no	29835			29835
Rzanovo	North Macedonia	C	Operating	Ni	no	24670			24670
Aghios Ioannis-Marmeiko (Lokris)	Greece	C	Not operating		no	24500			24500
Sulmierzyce Północ	Poland	C	Not operating		no	22640			22640
Mamez	Albania	C			no	21415			21415
Løkken	Norway	C	Abandoned		no	4200		16800	21000
Sakatti	Finland	C	Not exploited		no	20424			20424
Nowa Sól	Poland	C	Not operating		no	15920			15920
Juomasuo	Finland	C	Not exploited		no	15656			15656
Enora	Germany	C	Not exploited		no	14422			14422
Kylylahti	Finland	C	Closed		no	7781		6149	13930
Ahmavaara	Finland	C	Not exploited		no	13144			13144
Veluce	Serbia	C			no	11200			11200
Sulitjelma	Norway	C	Abandoned		no	1801		7635	9436
Rönnbäcksnäset	Sweden	C	Not exploited		no	8400			8400
Sundsberget	Sweden	C	Not exploited		no	8400			8400
Vuonos-Cu	Finland	C	Closed		no	1064		7270	8334
Haarakumpu	Finland	C	Not exploited		no	7769			7769
Kuervitikko	Finland	C	Not exploited		no	7095			7095
Luikonlahti	Finland	C	Closed		no			7035	7035
Ruossakero	Finland	C	Not exploited		no	6736			6736
Njeretjakke	Sweden	C	Not exploited		no	5745			5745
Hautalampi	Finland	C	Not exploited		no	2165	3559*		5725
Campo de Calatrava (Bolaños)	Spain	C	Not operating		no	5700			5700
Chervoniy Yar	Ukraine	C	Not operating		no	5674			5674
Ieropigi	Greece	C	Not operating		no	5400			5400
Bruvann	Norway	C	Abandoned		no	2745		2460	5205
Rajapalot	Finland	C	Not exploited		no	5173			5173
Kaukua	Finland	C	Not exploited		no	4824			4824
Derenyukhynske	Ukraine	C	Not operating		no		425*	4175	4600

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total en-dowment (t)
Bitinckë	Albania	C	Operating in-termittently	Ni	no	4590			4590
Gllavica	Kosovo[4]	C	Operating	Ni	no	4553			4553
Wartowice	Poland	C	Closed		no	4290			4290
Pappilanmäki	Finland	C	Not exploited		no	4111			4111
Älgliden	Sweden	C	Not exploited		no	3900			3900
Vinberget	Sweden	C	Not exploited		no	3600			3600
Ertelien	Norway	C	Closed		no	3300			3300
Lypovenkivske	Ukraine	C	Not operating		no		2441*	859	3300
Lokridha	Greece	C	Not operating		no	3200			3200
Devladivske	Ukraine	C	Not operating		no		3142*		3142
Kiskamavaara	Sweden	C	Not exploited		no	3068			3068
Vähäjoki	Finland	C	Not exploited		no	3045			3045
Konttijärvi	Finland	C	Not exploited		no	3010			3010
Tarnavatske	Ukraine	C	Not operating		no		2934*		2934
Saramäki	Finland	C	Not exploited		no	2924			2924
Mozów	Poland	C	Not operating		no	2660			2660
Pahtavuoma	Finland	C	Not exploited		no	2585			2585
Vuonos-Ni	Finland	C	Not exploited		no	2240			2240
Perttilahti	Finland	C	Not exploited		no	2118			2118
Skuterud	Norway	C	Abandoned		no			2000	2000
Punta Corna	Italy	C	Pending ap-proval		yes				2000^{m}
Hodkovce	Slovakia	C			yes				2000^{m}

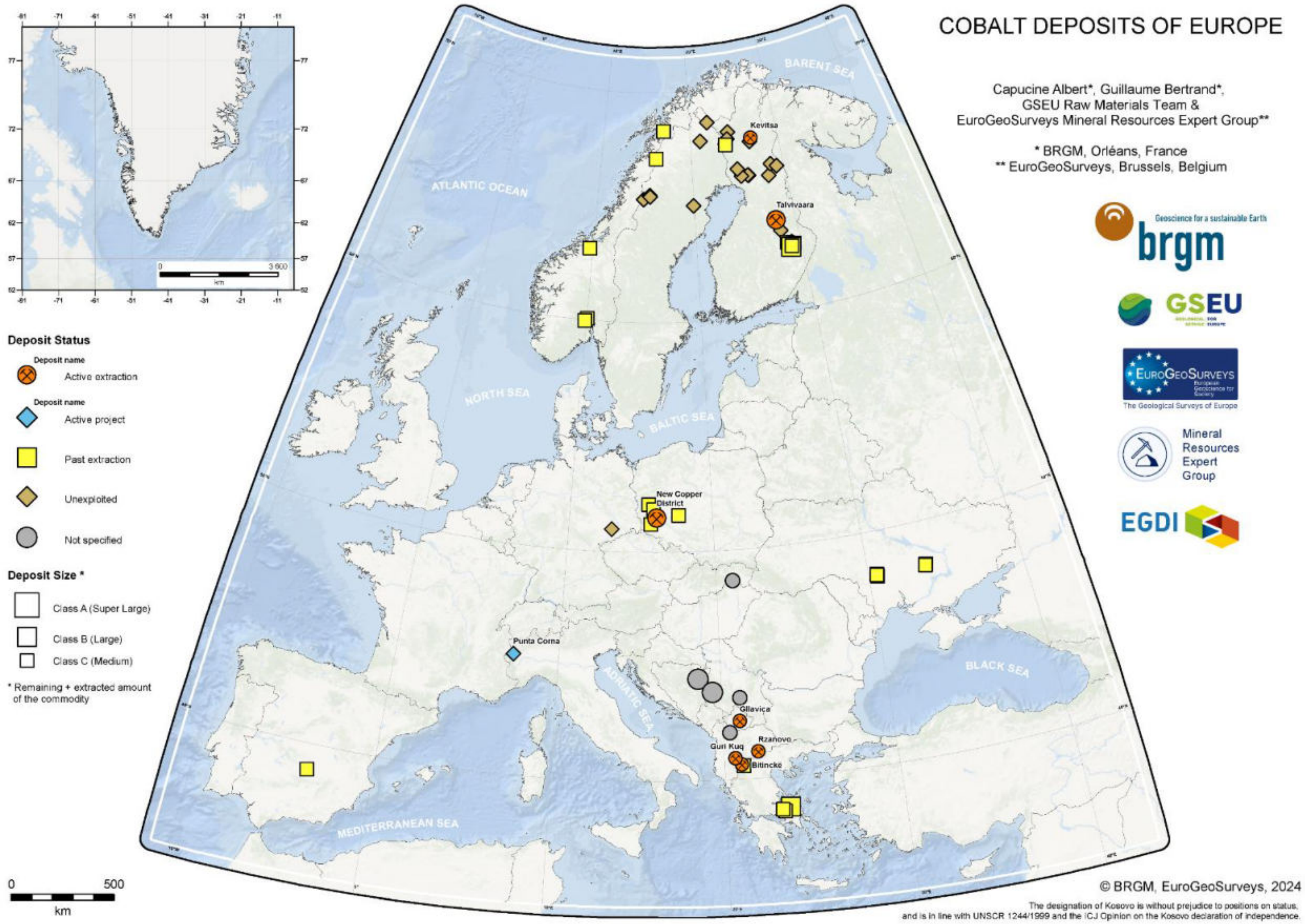
^{m} minimum estimate
* reserves not included in resources

Table 18: *Cobalt resources/reserves from the main deposits in Europe.*

Country	Remaining resources – cobalt contained (tons of Co metal)	Category
Albania	**65980**	4 – historical or non-compliant
Finland	**110736** **305182** **73764**	1 – mineral reserves 2 – mineral resources 4 – historical or non-compliant
Germany	**14422**	4 – historical or non-compliant
Greece	**106100**	4 – historical or non-compliant
Kosovo[4]	**4553**	3 – compliant historical
North Macedonia	**24670**	4 – historical or non-compliant
Norway	**6045** **6001**	2 – mineral resources 4 – historical or non-compliant
Poland	**200630**	2 – mineral resources
Serbia	**371200**	4 – historical or non-compliant
Spain	**5700**	4 – historical or non-compliant
Sweden	**20400** **12713**	2 – mineral resources. 4 – historical or non-compliant
Ukraine	**8942** **5674**	1 – mineral reserves 3 – compliant historical

[4] This designation (of Kosovo) is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

Figure 11: *Map of cobalt deposits in Europe.*



3.9. Coking Coal

Coking coal, also known as metallurgical coal, is a type of bituminous coal with specific properties that allow it to be converted into coke – a high-carbon, porous material essential for steelmaking. Coking coal often occurs interlayered with thermal (less valuable) coal, and cannot be extracted selectively. For this reason, it is often difficult to estimate the proportion of "coking coal quality" coal in a given coal field.

Table 19: *Main European coking coal deposits identified in 2024. Tonnages are in tons of coking coal.*

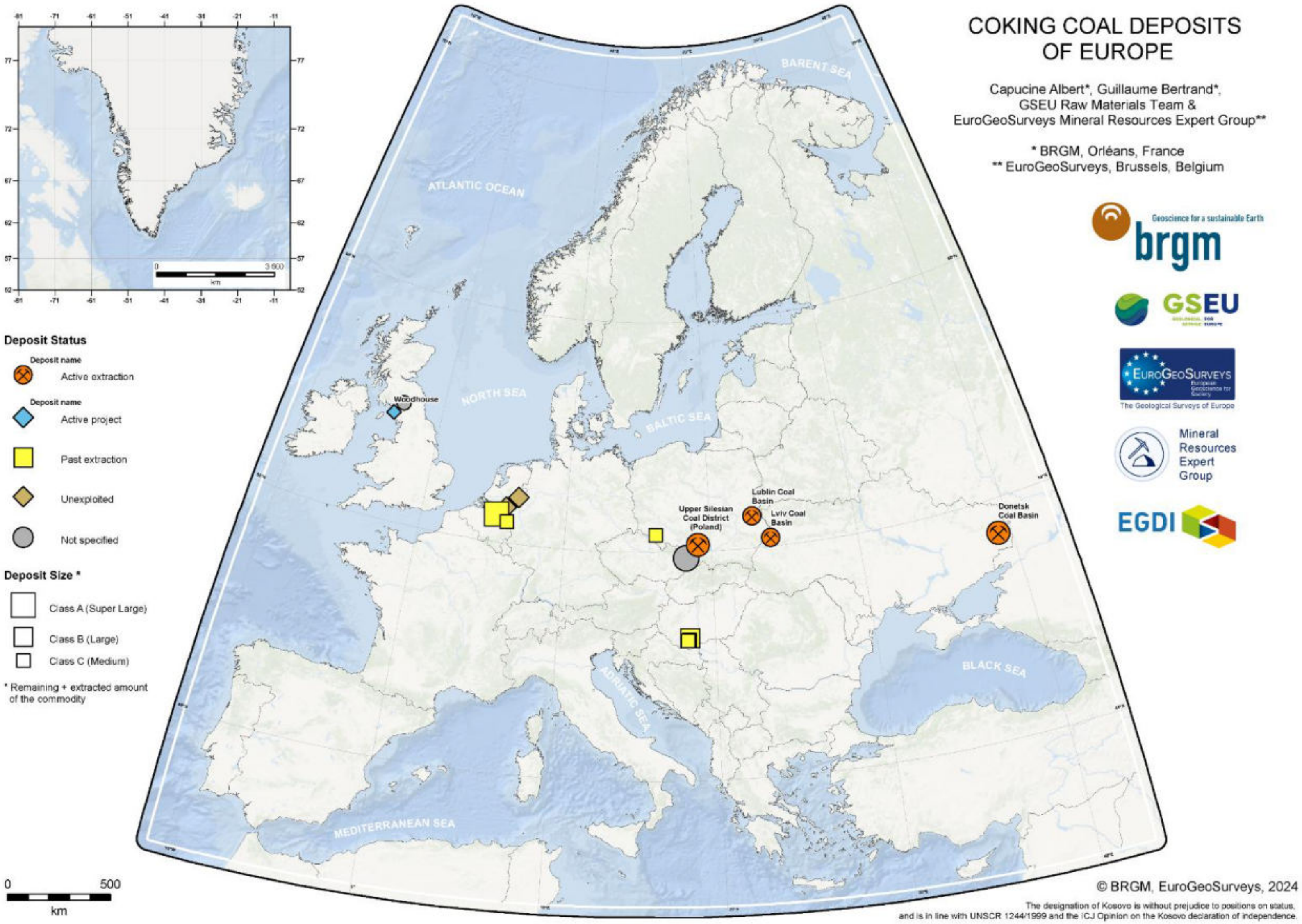
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Donetsk Coal Basin	Ukraine	A	Operating	Coal	no		68281111000*		68281111000
Limburg	Belgium	A	Closed		no	37500000000	4000000000	441062045	37941062045
Upper Silesian Coal District (Poland)	Poland	A	Operating	Coal	no	14133250000	1599060000*		15732310000
Upper Silesian Coal District (Czechia)	Czechia	A			yes				10000000000[m]
Achterhoek	The Netherlands	B	Not exploited		no	4550000000		0	4550000000
Lviv Coal Basin	Ukraine	B	Operating	Coal	no		1819937000*		1819937000
Peel	The Netherlands	B	Not exploited		no	1650000000		0	1650000000
Lublin Coal Basin	Poland	B	Operating	Coal	no	1496370000	65250000*		1561620000
Máza-Váralja	Hungary	B	Closed		no	1241169130		0	1241169130
Zuid-Limburg	The Netherlands	C	Historic		no	296000000		291000000	587000000
Lower Silesian Coal Basin	Poland	C	Not operating		no	273540000	190000*		273730000
Woodhouse	UK	C	Pending approval		no	216000000			216000000
Hosszúhetény	Hungary	C	Closed		no	205369500			205369500
Zobák	Hungary	C	Closed		no	136699210		63000000	199699210
Pécsbánya	Hungary	C	Closed		no	124073460		40000000	164073460
Lochinvar	UK	C			no	111000000			111000000

[m] minimum estimate
* reserves not included in resources

Table 20: *Coking coal resources/reserves from the main deposits in Europe.*

Country	Remaining resources – coking coal contained (tons)	Category
Belgium	**4000000000** **33500000000**	1 – mineral reserves 4 – historical or non-compliant
Hungary	**1707311300**	2 – mineral resources
The Netherlands	**6496000000**	4 – historical or non-compliant
Poland	**1664500000** **15903160000**	1 – mineral reserves 2 – mineral resources
UK	**111000000** **216000000**	2 – mineral resources 4 – historical or non-compliant
Ukraine	**70101048000**	1 – mineral reserves

Figure 12: *Map of coking coal deposits in Europe.*



3.10. Copper (Cu)

Copper in Europe primarily occurs in several key types of deposits: 1) sediment-hosted deposits, such as the Kupferschiefer in Poland, featuring copper-rich shales or sandstones with significant silver by-products, 2) volcanogenic massive sulfide (VMS) deposits, prominent in Spain and Portugal, which are major sources of copper, zinc, and polymetallic ores, 3) porphyry deposits, mostly present in the Balkans, and 4) smaller-scale skarn deposits found in regions like the Alps, often associated with other metals like gold or molybdenum.

Table 21: *Main European copper deposits identified in 2024. Tonnages are in tons of Cu metal.*

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
New Copper District	Poland	A	Operating	Cu, Ag, Pb, Ni, Re, Au	no	43394000	20966000*	443000	64803000
Nowa Sól	Poland	A	Not operating		no	10960000			10960000
Aitik	Sweden	B	Operating	Cu, Ag, Au	no	1598000	2628900*	2270100	6497000
Sulmierzyce Północ	Poland	B	Not operating		no	5652000			5652000
Borska reka	Serbia	B	Under develop-ment		no	5383911	730593		5383911
Recsk	Hungary	B	Closed		no	4712687		19500	4732187
Mozów	Poland	B	Not operating		no	4587000			4587000
Neves Corvo	Portugal	B	Operating	Cu, Zn, Pb	no	1457000	420000	1184544	2641544
Rosia Poieni	Romania	B	Operating	Cu	no	2370500			2370500
Laver	Sweden	B	Not exploited		no	2114200			2114200
Talvivaara	Finland	B	Operating	Ni, Co	no	1305920	735280*		2041200
Majdanpek	Serbia	B	Operating	Cu, Au	no	2026335	558306		2026335
Mansfeld	Germany	B	Historic		no			2009800	2009800
Minas de MATSA	Spain	B	Operating	Cu, Zn, Pb	no	1833700	574000	150000	1983700
Veliki Krivelj	Serbia	B	Operating	Cu	no	1858709	514730		1858709
Moldova Noua	Romania	B	Closed		no	1800000			1800000
Minas de Riotinto	Spain	B	Operating	Cu, Ag	no	1560000	702750	142500	1702500
Bucium-Tarnita	Romania	B	Not exploited		no	1700000			1700000
Cukaru Peki	Serbia	B	Operating	Cu, Au	no	1697800			1697800
Aljustrel	Portugal	B	Operating	Cu	no	1615000		6300	1621300
Las Cruces	Spain	B	Operating	Cu	no	699990	472000	801923	1501913
Spremberg	Germany	B	Feasibility		no	1486000			1486000
Sangerhausen	Germany	B	Historic		no	860000		619200	1479200
Skouries	Greece	B	Under develop-ment		no	1385000			1385000
Wartowice	Poland	B	Closed		no	1366000			1366000
Żary	Poland	B	Not operating		no	1276000			1276000
Kevitsa	Finland	B	Operating	Ni, Cu, Co, Pt, Pd, Au	no	586749	257794*	256835	1101378
La Zarza	Spain	B	Closed		no	780000		280000	1060000
Viscaria	Sweden	B	Closed		no	818400		221604	1040004
Mali Krivelj	Serbia	B			no	1024654			1024654
Elatsite	Bulgaria	B							1000000[m]
Assarel	Bulgaria	B							1000000[m]
Varine	Montene-gro	B							1000000[m]
Cavnic	Romania	B	Closed		yes				1000000[m]
Cerovo	Serbia	C	Operating	Cu	no	990071	319500		990071
Outokumpu	Finland	C	Closed		no			956499	956499

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Aznalcóllar	Spain	C	Under develop-ment		no	920800			920800
Nussir	Norway	C	Feasibility		no	854100			854100
Sakatti	Finland	C	Not exploited		no	844488			844488
Mavrovouni	Cyprus	C	Abandoned		no	56000		742894	798894
Sulitjelma	Norway	C	Abandoned		no	264744		478460	743204
Pyhäsalmi	Finland	C	Closed		no	100074	59262*	541747	701083
Løkken	Norway	C	Abandoned		no	138000		552000	690000
Rovina Valley	Romania	C	Pending approval		no	689930	196519		689930
Touro	Spain	C	Feasibility		no	680000	390000		680000
Coed Y Brenin	UK	C	Historic		no	594000			594000
Richelsdorf	Germany	C	Historic		no	168000		416500	584500
Tharsis	Spain	C	Under develop-ment		no	574000			574000
Falu gruva	Sweden	C	Closed		no	12400		52245	564645
Masa Valverde	Spain	C	Under develop-ment		no	560000			560000
Rouez	France	C			no	540000			540000
Talagiu	Romania	C	Not exploited		no	525000			525000
Kristineberg	Sweden	C	Operating	Cu, Pb, Zn	no	76620	42880*	319600	439100
Hannukainen	Finland	C	Closed		no	377910		14814	392724
Nautanen	Sweden	C	Not exploited		no	382500			382500
S. Domingos	Portugal	C	Abandoned		no	62500		312500	375000
Rammelsberg	Germany	C	Historic		no			351000	351000
Ahmavaara	Finland	C	Not exploited		no	328598			328598
Gavião	Portugal	C	Under develop-ment		no	326160			326160
Valja Strz	Serbia	C			no	281320	103905		281320
Adakfältet	Sweden	C	Closed		no	142500		120460	262960
Skouriotissa	Cyprus	C	Closed		no	0		258502	258502
Bucim	North Macedo-nia	C	Operating	Cu, Au	no	255000			255000
Gjegjan	Albania	C	Operating	Cu	no	133200		114230	247430
Joma	Norway	C	Feasibility		no	72000		170650	242650
Los Frailes	Spain	C	Under develop-ment		no	221670			221670
Nowy Kościół	Poland	C	Closed		no	218000			218000
Kraku Bugaresku-Ce-mentacija	Serbia	C			no	210278	84969		210278
Stekenjokk	Sweden	C	Closed		no	112100		80270	192370
Dingelvik	Sweden	C	Not exploited		no	182700			182700
Rockliden	Sweden	C	Not exploited		no	173000			173000
Niecka Grodziecka	Poland	C	Closed		no	171000			171000
Parys Mountain	UK	C	Feasibility		no	161659			161659
Vihanti	Finland	C	Closed		no	31158		128682	159840
Tverrfjellet	Norway	C	Closed		no			150000	150000
Bor	Serbia	C	Operating	Cu, Au	no	146480	74083		146480
Munella	Albania	C	Operating	Cu	no	118776		24682	143458
Garpenbergsfältet	Sweden	C	Operating	Cu, Pb, Zn, Ag, Au	no	49264	50500*	40960	140724
Deva	Romania	C	Not operating		no	140000			140000
Chessy les Mines	France	C	Historic		no	124000		15000	139000
Calabona	Italy	C	Abandoned		no	132300		810	133110
Vuonos-Cu	Finland	C	Closed		no	13376		117807	131183
Kongens gruve	Norway	C	Closed		no	71253		53865	125118

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Renström	Sweden	C	Operating	Cu, Pb, Zn	no	10000	16192*	97500	123692
Henneviken	Sweden	C	Not exploited		no	123375			123375
Alconchel	Spain	C	Under develop-ment		no	120000			120000
Fisoka-OP65-Allatina	Greece	C	Not operating		no	120000			120000
Boliden	Sweden	C	Closed		no			117368	117368
Lousal	Portugal	C	Abandoned		no	60000		56700	116700
Granliden	Sweden	C	Not exploited		no	113520			113520
Tallberg	Sweden	C	Not exploited		no	112500			112500
Zinkgruvan	Sweden	C	Operating	Zn, Pb, Cu, Ag	no	72840	31548	37989	110829
Altan-Tepe	Romania	C	Not operating		no	71500		38500	110000
Kylylahti	Finland	C	Closed		no	26993		74268	101261
Mitterberg-Nordrevier	Austria	C	Abandoned		yes				100000[m]
Mitterberg	Austria	C	Abandoned		yes				100000[m]
Chelopech	Bulgaria	C							100000[m]
Medet	Bulgaria	C							100000[m]
Prohorovo	Bulgaria	C							100000[m]
Madan ore field	Bulgaria	C							100000[m]
Popovo Dere	Bulgaria	C							100000[m]
Orlovo Gnezdo	Bulgaria	C							100000[m]
Vozdol	Bulgaria	C							100000[m]
Karlievo	Bulgaria	C							100000[m]
Kiseljak	Bosnia & Herze-govina	C							100000[m]
Aherlow	Ireland	C							100000[m]
Kazandol	North Macedo-nia	C							100000[m]
Borov Dol	North Macedo-nia	C							100000[m]
Zlatica	North Macedo-nia	C							100000[m]
Kadiica	North Macedo-nia	C							100000[m]
Voia	Romania	C	Closed		yes				100000[m]
Valea Tisei	Romania	C	Closed		yes				100000[m]
Muncaceasca-W	Romania	C	Closed		yes				100000[m]
Novicior-Viseu	Romania	C	Closed		yes				100000[m]
Baia Borsa-Burloaia	Romania	C	Closed		yes				100000[m]
Medies	Romania	C	Closed		yes				100000[m]
Baia de Arama	Romania	C	Closed		yes				100000[m]
Oravita	Romania	C	Closed		yes				100000[m]
Sasca	Romania	C	Closed		yes				100000[m]
Fagu Cetatii	Romania	C	Closed		yes				100000[m]
Lesu Ursului	Romania	C	Closed		yes				100000[m]
Fundu Moldovei	Romania	C	Closed		yes				100000[m]
Gladna Montana-Roza-lia	Romania	C	Not exploited		yes				100000[m]
Balan	Romania	C	Not operating		yes				100000[m]
Špania dolina-Glezúr-Piesky-Mária šachta	Slovakia	C			yes				100000[m]
Avoca	Ireland	C	Abandoned						100000[m]

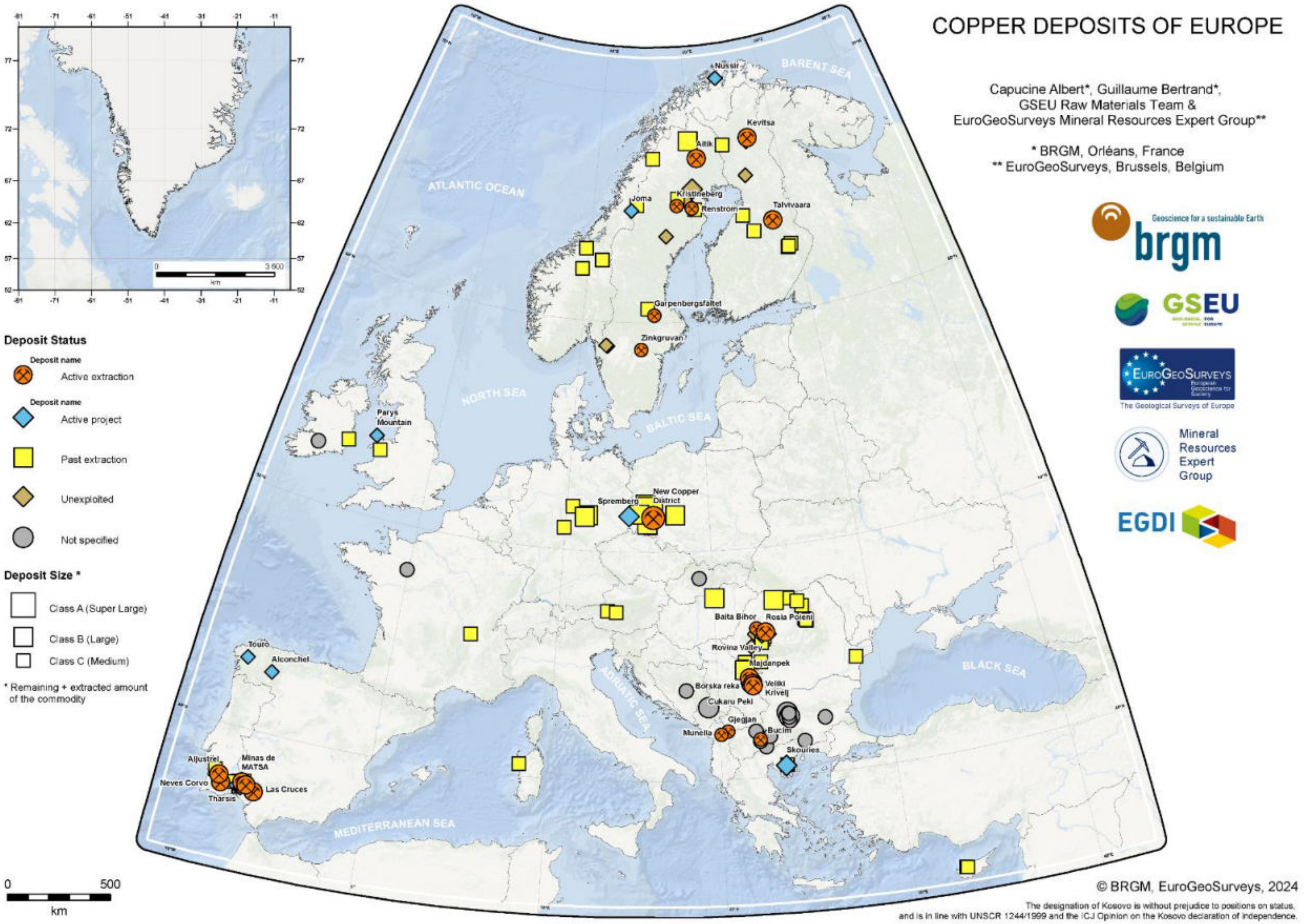
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Baita Bihor	Romania	C	Operating	Cu, Zn, Pb, Au, Ag	no	15686			15686

m minimum estimate
* reserves not included in resources

Table 22: *Copper resources/reserves from the main deposits in Europe.*

Country	Remaining commodity – copper contained (tons of Cu metal)	Category
Albania	**251976**	2 – mineral resources
Cyprus	**56000**	4 – historical or non-compliant
Finland	**1052336** **3206197** **409067**	1 – mineral reserves 2 – mineral resources 3 – compliant historical
France	**664000**	4 – historical or non-compliant
Germany	**1486000** **1028000**	2 – mineral resources 4 – historical or non-compliant
Greece	**1385000** **120000**	2 – mineral resources 4 – historical or non-compliant
Hungary	**4712687**	2 – mineral resources
Italy	**132300**	4 – historical or non-compliant
North Macedonia	**255000**	4 – historical or non-compliant
Norway	**926100** **473997**	2 – mineral resources 4 – historical or non-compliant
Poland	**20966000** **67624000**	1 – mineral reserves 2 – mineral resources
Portugal	**420000** **1037000** **2063660**	1 – mineral reserves 2 – mineral resources 4 – historical or non-compliant
Romania	**196519** **580597** **6535500**	1 – mineral reserves 2 – mineral resources 4 – historical or non-compliant
Serbia	**2386086** **11233472**	1 – mineral reserves 2 – mineral resources
Spain	**2138750** **3314940** **1354000** **1142470**	1 – mineral reserves 2 – mineral resources 3 – compliant historical 4 – historical or non-compliant
Sweden	**2770020** **5683995** **378375**	1 – mineral reserves 2 – mineral resources 4 – historical or non-compliant
UK	**161659** **594000**	2 – mineral resources 4 – historical or non-compliant

Figure 13: *Map of copper deposits in Europe.*



3.11. Feldspar

Feldspar is more accurately defined as a group of rock-forming minerals, of which anorthite, albite and potassium feldspar are the main endmembers. Nepheline syenite is an alternative material for feldspar.

Table 23: *Main European feldspar deposits identified in 2024. Tonnages are in tons of feldspar.*

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Lillebukt	Norway	A	Operating	Nepheline syenite	no	400000000			400000000
Majoqqap Qaava	Greenland	B	Not exploited		no	59000000			59000000
Maciejowa	Poland	B	Not operating		no	53928410			53928410
Funtana Tenesoli	Italy	B	Operating	Feldspar	no		30000000*		30000000
Dziwiszów	Poland	B	Not operating		no	25476000			25476000
Qaqortorssuaq, Najaat-White Mountain	Greenland	B	Operating intermittently	Anorthosite	no	21800000			21800000
Kamienica Mała	Poland	B	Not operating		no	21695000			21695000
Kopaniec	Poland	B	Not operating		no	13823000			13823000
Pernighera Surlo	Italy	B	Closed		no	1500000		10973313	12473313
Karpniki	Poland	B	Operating intermittently	Feldspar	no	10377350	2590350		10377350
Mracnice	Czechia	B			yes				10000000[m]
Krasno-Vysoky Kamen	Czechia	B			yes				10000000[m]
Monte sa Pira	Italy	B	Not operating		yes				10000000[m]
Rosia Montana	Romania	B	Closed		yes				10000000[m]
Tréguennec-Prat-ar-Hastel	France	C	Not exploited		no	8000000			8000000
Proszowa-Kwieciszowice	Poland	C	Not operating		no	7596650			7596650
Azovske	Ukraine	C	Not operating		no	6684990			6684990
Barroso	Portugal	C	Under development		no	6134400			6134400
Strzeblów	Poland	C	Operating	Feldspar	no	5796830	5772030	15030	5811860
Bakhtynske	Ukraine	C	Not operating		no		2983700*		2983700
Molinu Falzu	Italy	C	Operating	Feldspar	no		2500000*		2500000
Monte Cuccureddu	Italy	C	Not operating		no		2400000*		2400000
Botro ai marmi	Italy	C	Operating	Feldspar	no		2200000*		2200000
Badu e Carru	Italy	C	Operating	Feldspar	no		2050000*		2050000
Guri i Zi	Albania	C	Not operating		no	2000000			2000000
Monte Mamas	Italy	C	Operating	Feldspar	no	2000000			2000000
Shevchenkivske	Ukraine	C	Not operating		no		1821380*		1821380
San Grato	Italy	C	Operating	Feldspar	no		1020000*		1020000
Bijela Voda	Bosnia & Herzegovina	C							1000000[m]
Mikulovice	Czechia	C			yes				1000000[m]
Velke Mezirici-Lavicky	Czechia	C			yes				1000000[m]
Ivancice-Nemcice	Czechia	C			yes				1000000[m]
Ledce-Hrusovany u Brna	Czechia	C			yes				1000000[m]
Majdalena	Czechia	C			yes				1000000[m]
Markvartice u Trebice	Czechia	C			yes				1000000[m]
Potucky	Czechia	C			yes				1000000[m]
Hrusovany u Brna	Czechia	C			yes				1000000[m]
Bratcice	Czechia	C			yes				1000000[m]
Vycapy	Czechia	C			yes				1000000[m]

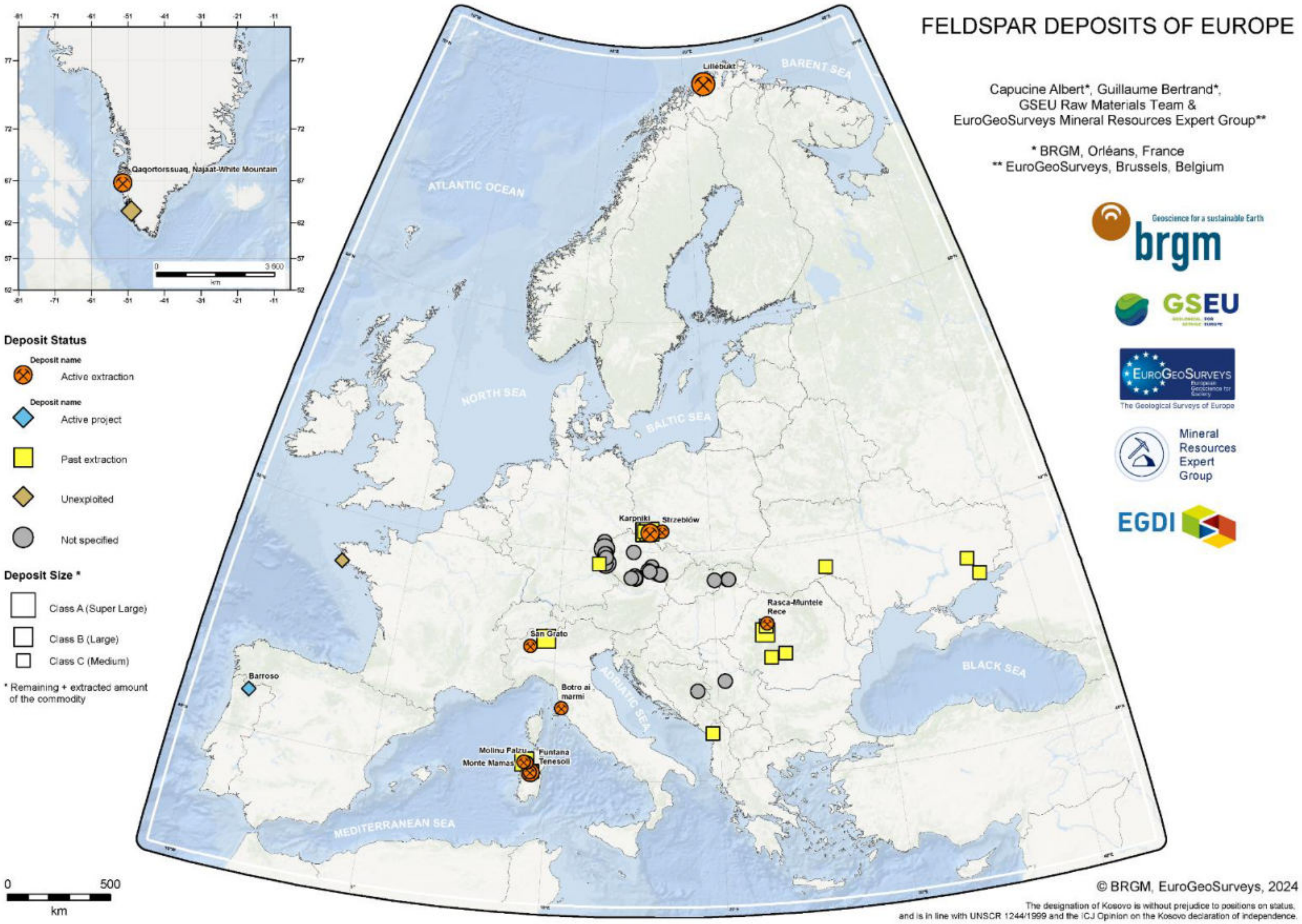
Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total en-dowment (t)
Meclov	Czechia	C			yes				1000000[m]
Halamky	Czechia	C			yes				1000000[m]
Zhorec	Czechia	C			yes				1000000[m]
Luzenicky	Czechia	C			yes				1000000[m]
Dvory nad Luznici-Tust	Czechia	C			yes				1000000[m]
Tust-Halamky	Czechia	C			yes				1000000[m]
Stihlice	Czechia	C			yes				1000000[m]
Hanov u Lestkova	Czechia	C			yes				1000000[m]
Benesovice	Czechia	C			yes				1000000[m]
Dvorec u Trebce	Czechia	C			yes				1000000[m]
V. Iara	Romania	C	Closed		yes				1000000[m]
Novaci	Romania	C	Closed		yes				1000000[m]
Cozia-V.Vâlsanului	Romania	C	Closed		yes				1000000[m]
Rasca-Muntele Rece	Romania	C	Operating	Feldspar	yes				1000000[m]
Garasi	Serbia	C							1000000[m]
Rudník	Slovakia	C			yes				1000000[m]
Nováčany	Slovakia	C			yes				1000000[m]
Revúčka	Slovakia	C			yes				1000000[m]
Cornelia Mine	Germany	C	Historic		no			1000000	1000000

[m] minimum estimate
* reserves not included in resources

Table 24: *Feldspar resources/reserves from the main deposits in Europe.*

Country	Remaining resources – feldspar contained (tons)	Category
Albania	**2000000**	2 – mineral resources
France	**8000000**	4 – historical or non-compliant
Greenland	**80800000**	2 – mineral resources
Italy	**40170000** **3500000**	1 – mineral reserves 4 – historical or non-compliant
Norway	**400000000**	4 – historical or non-compliant
Poland	**8362380** **130330860**	1 – mineral reserves 2 – mineral resources
Portugal	**6134400**	2 – mineral resources
Ukraine	**4805080** **6684990**	1 – mineral reserves 3 – compliant historical

Figure 14: *Map of feldspar deposits in Europe.*



3.12. Fluorspar (Fluorite, CaF_2)

Fluorite (CaF_2), also known as fluorspar, occurs in several types of deposits: 1) in hydrothermal veins associated with quartz, baryte, calcite, sulfides, with sizeable deposits located in the Asturias region in Spain, France, the United Kingdom and in Bavaria and the Black Forest regions in Germany, 2) in alkaline igneous rocks, found in regions like Norway, and 3) in sedimentary deposits, such as in France.

Table 25: *Main European fluorspar deposits identified in 2024. Tonnages are in tons of CaF_2.*

Name	Country	Class	Deposit status	Commodi-ties currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total en-dowment (t)
Lújar-San Isidro	Spain	A	Operating	Fluorspar	no	95561440	10917605	54331	95615771
Lupión	Spain	A	Under development		no	24622005	7958340		24622005
Minas de MINERSA	Spain	A	Operating	Fluorspar	no	10000000		154115	10154115
Pianciano	Italy	A	Operating	Fluorspar	no	1059630	600000	7000000	8059630
Clara	Germany	A	Operating	Fluorspar, baryte	no	780000		7000000	7780000
Acquaforte	Italy	A	Closed		no	7000000		20000	7020000
Silius	Italy	A	Under development		no	3000000	2200000	2200000	5200000
Prestavel	Italy	B	Closed		no	2500000		2044000	4544000
Novopoltavske	Ukraine	B	Not operating		no		4323813*		4323813
Bakhtynske	Ukraine	B	Not operating		no	1200000	2510500*		3710500
Wölsendorf-Nabburg	Germany	B	Historic		no			3600000	3600000
Schönbrunn-Bösenbrunn	Germany	B	Closed		no	1725000		1220000	2945000
Storuman	Sweden	B	Not exploited		no	2828170			2828170
Escaro	France	B	Historic		no			2060000	2060000
Phönix (Gehren)	Germany	B	Feasibility		no	2000000			2000000
Käfersteige	Germany	B	Historic		no	1000000		1000000	2000000
Lassedalen	Norway	B	Abandoned		no	984000		984000	1968000
Wieden district	Germany	B	Closed		no	620000		1260000	1880000
Schauinsland	Germany	B	Closed		no	500000		1200000	1700000
Pokrovo-Kyreivske	Ukraine	B	Not operating		no		1433000*		1433000
Le Burc	France	B	Historic		no	840000		560000	1400000
Fontsante	France	B	Historic		no	350000		1020000	1370000
Pierre-Perthuis	France	B			no	1370000			1370000
Montroc	France	B	Closed		no			1272000	1272000
Niederschlag	Germany	B	Operating	Fluorspar, baryte	no	1150000		100000	1250000
Torgola	Italy	B	Historic		no	1200000		40000	1240000
Vallarsa	Italy	B	Historic		no	1114000		80000	1194000
Antully-Marquisat	France	B			no	1190000			1190000
Moldava	Czechia	B			yes				1000000[m]
Kovarska	Czechia	B			yes				1000000[m]
Probostov-odkaliste Pritkov	Czechia	B			yes				1000000[m]
Langeac	France	C	Historic		no			970000	970000
Maine-Reclesne	France	C	Historic		no	480000		480000	960000
Courcelles-Frémoy	France	C	Historic		no	960000			960000
Le Moulinal (Rayssac)	France	C	Historic		no			943000	943000
La Charbonnière-Châ-tenet	France	C	Historic		no	448000		350000	798000
Pontaubert	France	C			no	646000			646000
Chaillac (Rossignol)	France	C	Closed		no	150000		440000	590000
Marigny-sur-Yonne	France	C	Historic		no	512000		10000	522000

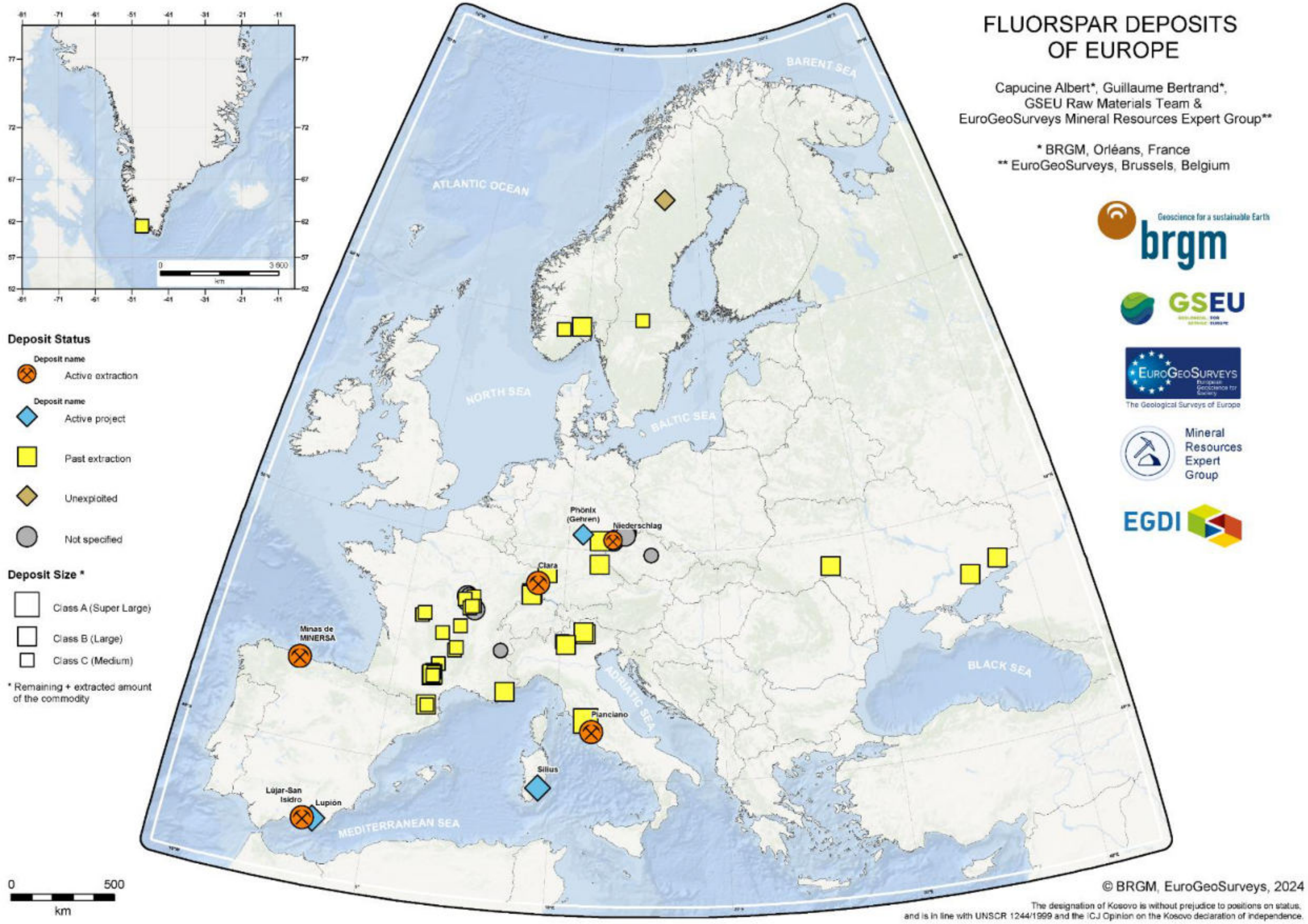
Name	Country	Class	Deposit status	Commodi-ties currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total en-dowment (t)
Pessens	France	C	Historic		no	520000			520000
Egreuil	France	C			no	400000			400000
Padiès	France	C	Historic		no	250000		136500	386500
Le Beix	France	C	Historic		no			386000	386000
Chavaniac-Lafayette	France	C	Historic		no	35000		341000	376000
Argentolle	France	C	Historic		no	300000		63000	363000
Le Sapey	France	C			no	300000			300000
Yxsjöberg	Sweden	C	Closed		no			291060	291060
Trébas	France	C	Historic		no	100000		175000	275000
Voltennes	France	C	Historic		no			250000	250000
Bois Feuillet	France	C			no	250000			250000
Ivittuut	Greenland	C	Not operating		no	250000			250000
Sahorre	France	C	Historic		no			249000	249000
Nizerolles	France	C	Closed		no	210000		10000	220000
Bestvina	Czechia	C			yes				200000[m]
Jilove u Decina-Sneznik	Czechia	C			yes				200000[m]
Laghetto di Polzone	Italy	C	Abandoned		yes				200000[m]
Tveitstå	Norway	C	Historic		no			200000	200000

[m] minimum estimate
* reserves not included in resources

Table 26: *Fluorite resources/reserves from the main deposits in Europe.*

Country	Remaining resources – fluorite contained (tons of CaF_2)	Category
France	**9311000**	4 – historical or non-compliant
Germany	**7775000**	4 – historical or non-compliant
Greenland	**250000**	4 – historical or non-compliant
Italy	**2800000** **13073630**	1 – mineral reserves 4 – historical or non-compliant
Norway	**984000**	2 – mineral resources
Spain	**18875945** **111307500**	1 – mineral reserves 4 – historical or non-compliant
Sweden	**2828170**	2 – mineral resources
Ukraine	**8267313** **1200000**	1 – mineral reserves 2 – mineral resources

Figure 15: *Map of fluorspar deposits in Europe.*



3.13. Gallium (Ga)

Gallium presents strong affinities with aluminium, and is therefore mainly recovered as a by-product during the processing of bauxite. It is also sometimes associated with zinc.

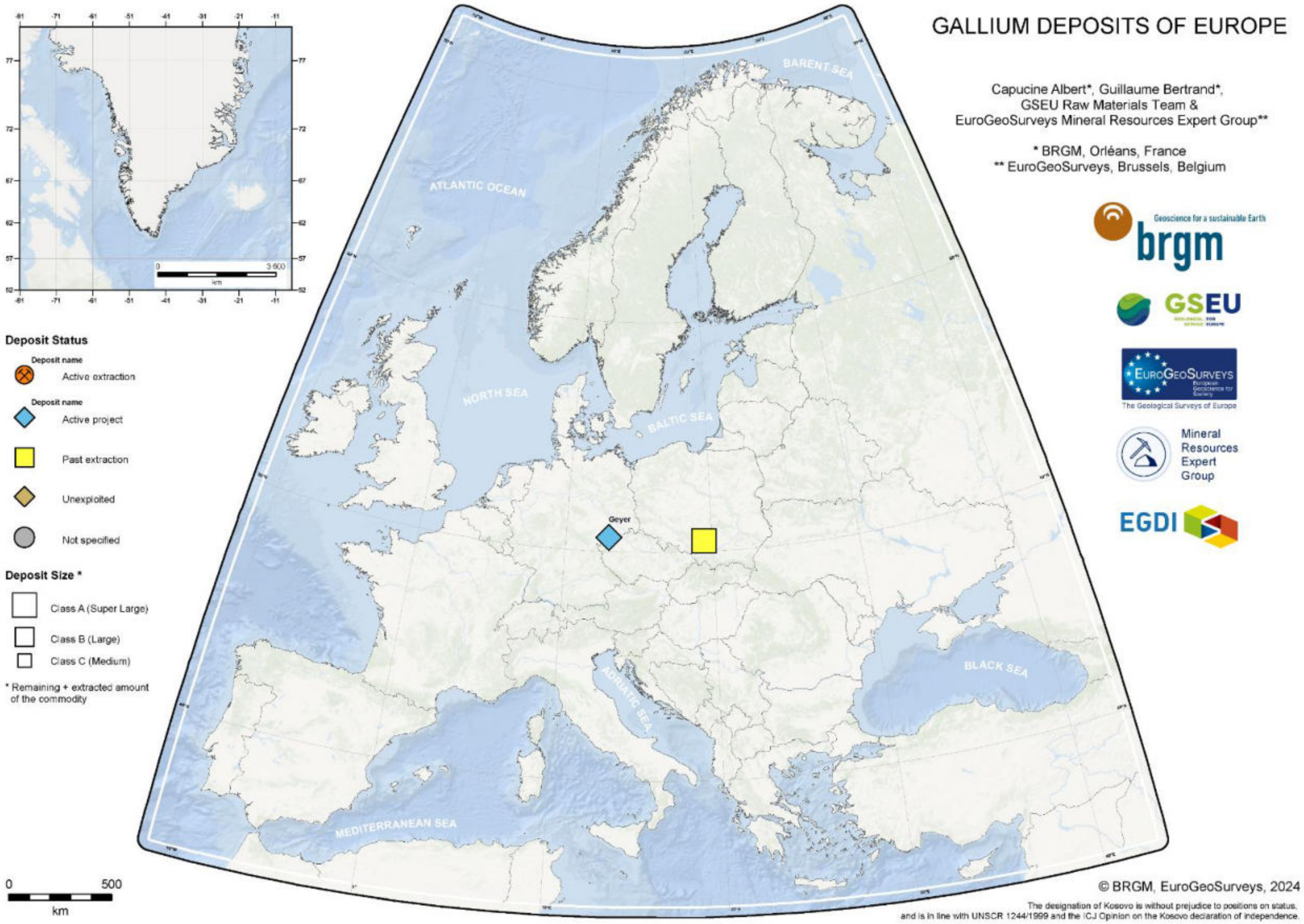
Table 27: *Main European gallium deposits identified in 2024. Tonnages are in tons of Ga metal.*

Name	Country	Class	Deposit status	Commodities currently mined	Confi-dential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Geyer	Germany	A	Feasibility		no	353			353
Zawiercie	Poland	A	Not operating		no	130			130

Table 28: *Gallium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – gallium contained (tons of Ga metal)	Category
Germany	**353**	2 – mineral resources
Poland	**130**	2 – mineral resources

Figure 16: _Map of gallium deposits in Europe._



3.14. Germanium (Ge)

Germanium presents strong affinities with zinc and organic matter, and is therefore present in some zinc deposits as well as some coal deposits. It is mainly produced as a by-product of zinc processing.

Table 29: *Main European germanium deposits identified in 2024. Tonnages are in tons of Ge metal.*

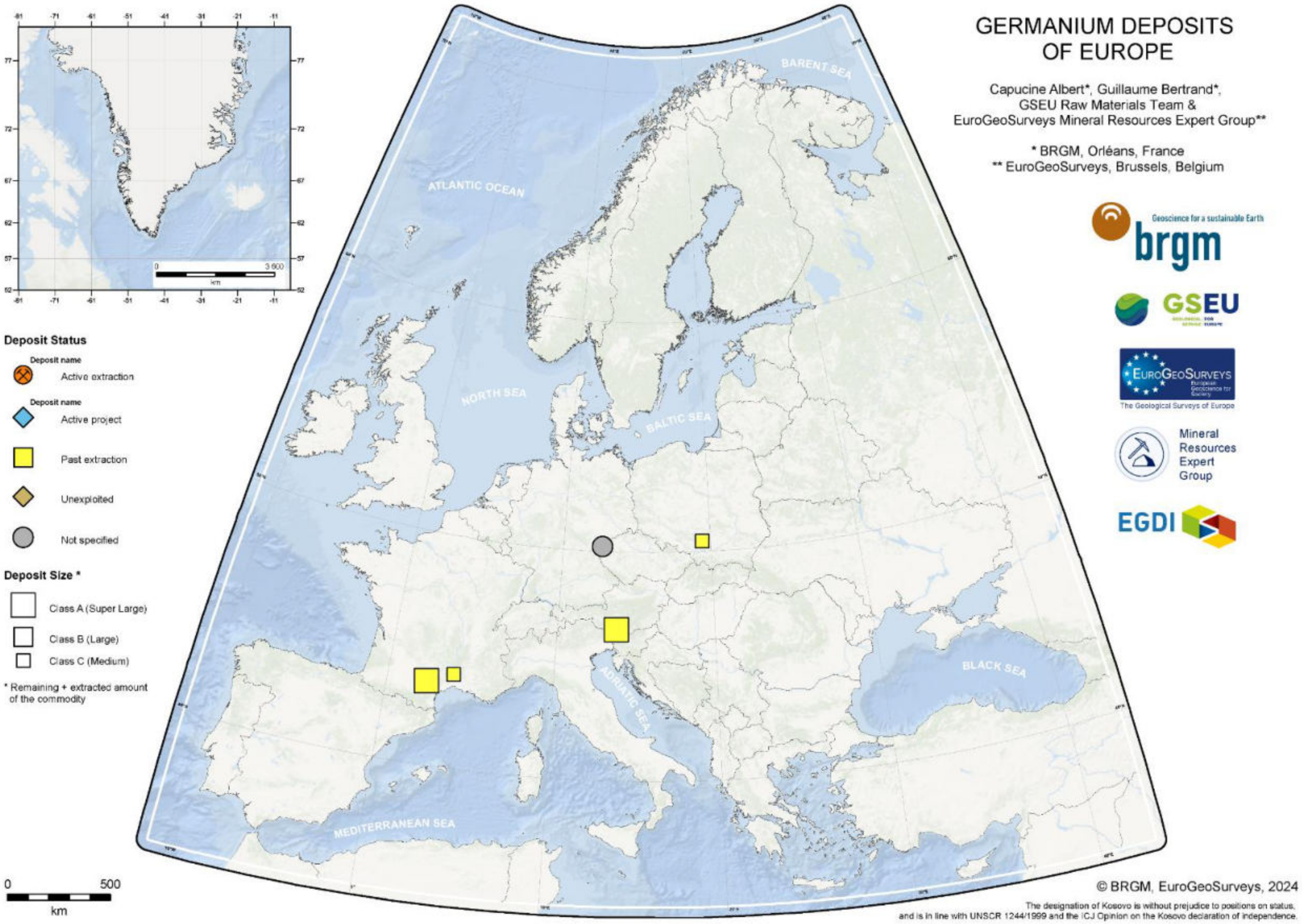
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Saint-Salvy	France	A	Historic		no	300		500	800
Bleiberg	Austria	A	Abandoned		yes				500[m]
Lomnice u Sokolova	Czechia	B			yes				100[m]
Zawiercie	Poland	C	Not operating		no	30			30
La Croix de Pallières	France	C	Historic		no			28	28

[m] minimum estimate

Table 30: *Germanium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – germanium contained (tons of Ge metal)	Category
France	**300**	4 – historical or non-compliant
Poland	**30**	2 – mineral resources

Figure 17: *Map of germanium deposits in Europe.*



3.15. Hafnium (Hf)

There are no primary hafnium ores in Europe, nor elsewhere in the world. All hafnium is recovered as a by-product from zirconium ores (mostly placer deposits), since both are contained in the mineral zircon.

Table 31: *Main European hafnium deposits identified in 2024. Tonnages are in tons of Hf metal.*

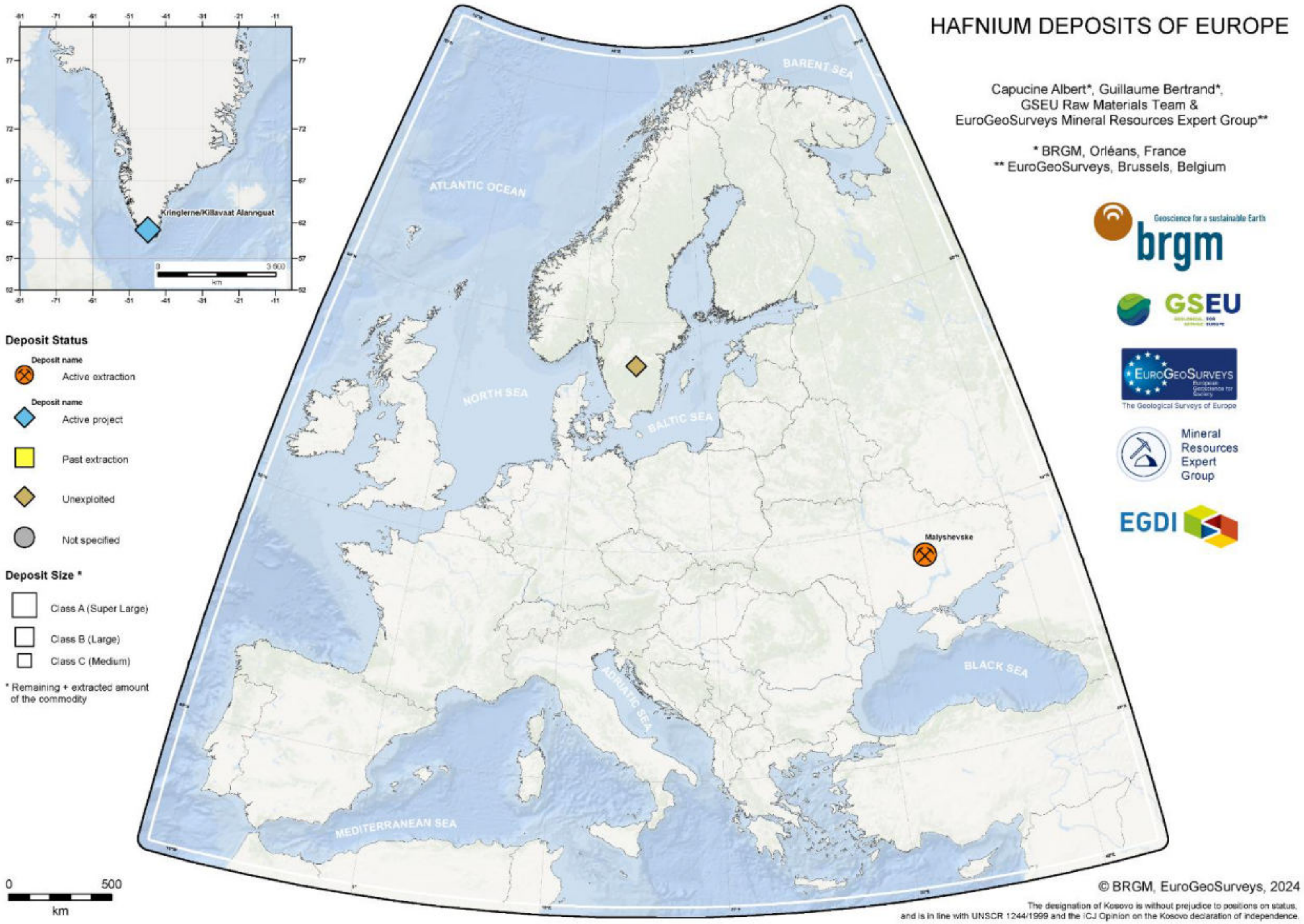
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total en-dowment (t)
Kringlerne/Killavaat Alan-nguat	Greenland	A	Under devel-opment		no	107500			107500
Malyshevske	Ukraine	A	Operating	Ti, Zr	no		10546*		10546
Norra Kärr	Sweden	B	Not exploited		no		6741		6741

* reserves not included in resources

Table 32: *Hafnium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – hafnium contained (tons of Hf metal)	Category
Greenland	**107500**	4 – historical or non-compliant
Sweden	**6741**	1 – mineral reserves
Ukraine	**10546**	1 – mineral reserves

Figure 18: *Map of hafnium deposits in Europe.*



3.16. Helium (He)

Helium is not sourced from a mineral. Instead, it is traditionally produced as a by-product of natural gas processing. Resources in Europe are not known at this stage.

3.17. Lithium (Li)

Lithium can be extracted from hard rock mining operations (e.g. of highly differentiated granites and pegmatites), and from geothermal brines (e.g. in the Upper Rhine Valley). Only hard rock deposits are evaluated here.

Table 33: *Main European lithium deposits identified in 2024. Tonnages are in tons of Li_2O.*

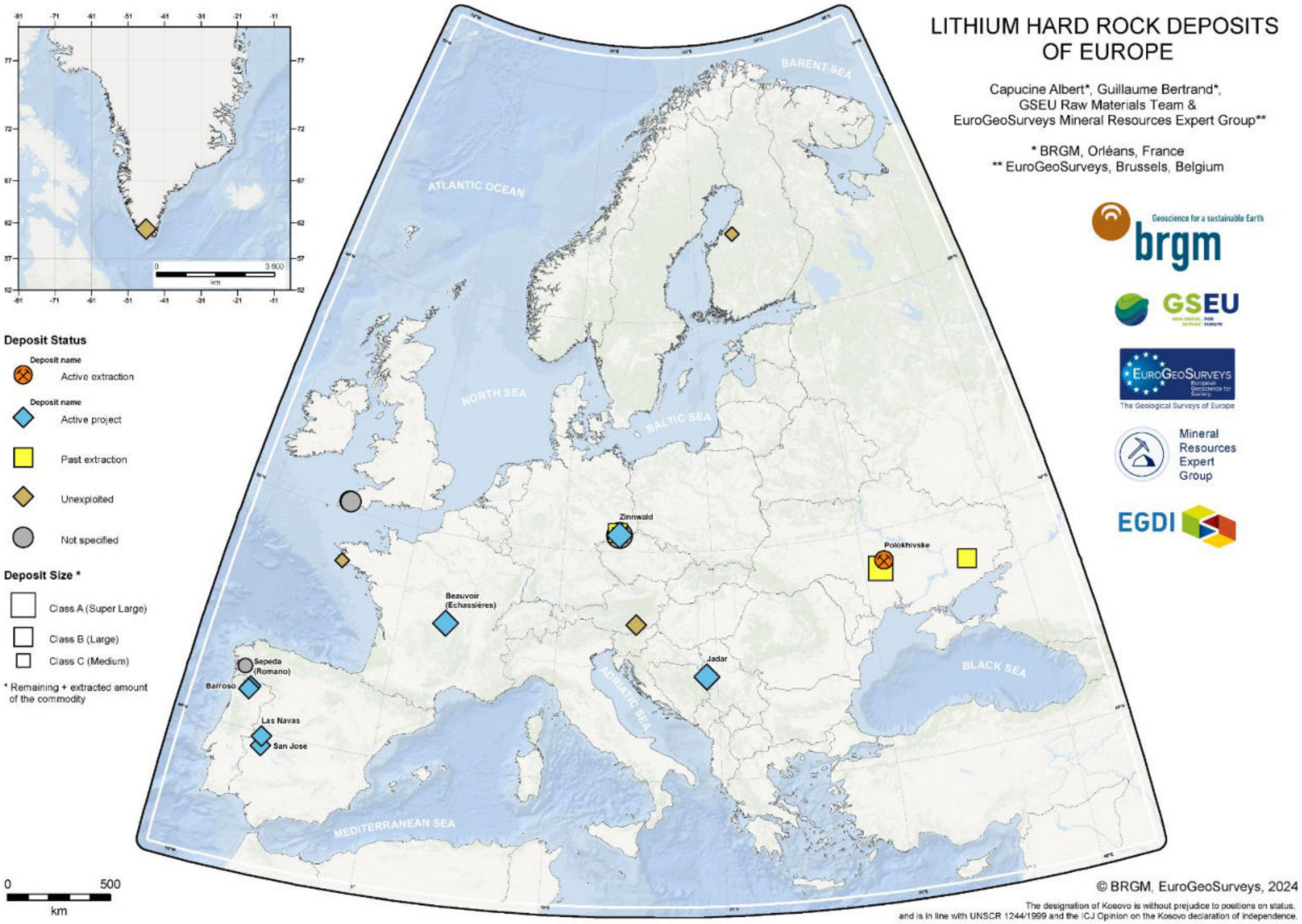
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Jadar	Serbia	A	Under development		no	2697003			2697003
Zinnwald	Germany	A	Feasibility		no	1078443			1078443
Beauvoir (Echassières)	France	A	Under development		no	1053000			1053000
Cínovec	Czechia	A			yes				1000000[m]
Dobra	Ukraine	A	Not operating		yes				1000000[m]
San Jose	Spain	B	Under development		no	678930	234360*		913290
St Austell Granite	UK	B			no	869613			869613
Las Navas	Spain	B	Under development		no	811370			811370
Kvanefjeld/Kuannersuit	Green-land	B	Not exploited		no	505885			505885
Sepeda (Romano)	Portugal	B	Under development		no	300000			300000
Barroso	Portugal	B	Under development		no	293400			293400
Weinebene	Austria	B	Not exploited		no	128500			128500
Sadisdorf	Germany	B	Closed		no	127284			127284
Trelavour	UK	B			no	124080			124080
Shevchenkivske	Ukraine	B	Not operating		yes				100000[m]
Polokhivske	Ukraine	B	Operating	Li	yes				100000[m]
Rapasaaret	Finland	C	Not exploited		no	94877			94877
Alberta I	Spain	C			no	90340			90340
Altenberg	Germany	C	Closed		no	71039			71039
Tréguennec-Prat-ar-Hastel	France	C	Not exploited		no	68680			68680

[m] minimum estimate; * reserves not included in resources

Table 34: *Lithium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – lithium contained (tons of Li_2O)	Category
Austria	**128500**	2 – mineral resources
Finland	**94877**	2 – mineral resources
France	**1121680**	4 – historical or non-compliant
Germany	**1078443** **198323**	2 – mineral resources 4 – historical or non-compliant
Greenland	**505885**	2 – mineral resources
Portugal	**593400**	2 – mineral resources
Serbia	**2697003**	2 – mineral resources
Spain	**234360** **1580640**	1 – mineral reserves 2 – mineral resources
UK	**993693**	2 – mineral resources

Figure 19: *Map of lithium hard rock deposits in Europe.*



3.18. Magnesium (Mg)

Magnesium is produced from two main sources: magnesium ores including dolomite ($CaMg(CO_3)_2$) and magnesite ($MgCO_3$), as well as natural brines. Economically viable production requires minimum magnesium contents: dolomite must have 8-10% Mg and magnesite 20-25% Mg.

Table 35: *Main European magnesium deposits identified in 2024. Unless stated otherwise, tonnages are in tons of* $MgCO_3$*.*

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Mieroszyno	Poland	A	Not operating		no	344758000			344758000
Swarzewo	Poland	A	Not operating		no	157033000			157033000
Pravdynske	Ukraine	A	Not operating		no		105134000*		105134000
Breitenau	Austria	A	Operating	Magnesite	yes				100000000[m]
Jelšava-Dúbrava Massif	Slovakia	A			yes				100000000[m]
Košice	Slovakia	A			yes				100000000[m]
Koigi	Estonia	B	Not exploited		no	21332854 (Mg metal)			21332854 (Mg metal)
Kalush-Golynske	Ukraine	B	Not operating		no		13679290* (Mg metal)		13679291 (Mg metal)
Kaisma	Estonia	B	Not exploited		no	4245253 (Mg metal)			4245253 (Mg metal)
Kurevere	Estonia	B	Operating	Dolomite	no	3102289 (Mg metal)			3102289 (Mg metal)
Klodawa	Poland	B	Operating	Salt	no	89292000	3464000*		92756000
Zdrada	Poland	B	Not operating		no	79587000			79587000
Chłapowo	Poland	B	Not operating		no	34500000			34500000
Gerakini	Greece	B	Operating	Magnesite	no	11215439			11215439
Augraben	Austria	B	Abandoned		yes				10000000[m]
Hohentauern	Austria	B	Abandoned		yes				10000000[m]
Sattlerkogel	Austria	B	Abandoned		yes				10000000[m]
Tux-Lanersbach	Austria	B	Abandoned		yes				10000000[m]
Hintertal	Austria	B	Abandoned		yes				10000000[m]
Millstätter Alpe	Austria	B	Operating	Magnesite	yes				10000000[m]
Oberdorf-Kaintaleck-Hohenburg	Austria	B	Operating	Magnesite	yes				10000000[m]
Wald am Schober-pass	Austria	B	Operating	Magnesite	yes				10000000[m]
Weißenstein	Austria	B	Operating	Magnesite	yes				10000000[m]
Budureasa	Romania	B	Not exploited		yes				10000000[m]
Lubeník	Slovakia	B			yes				10000000[m]
Rovné	Slovakia	B			yes				10000000[m]
Uderiná	Slovakia	B			yes				10000000[m]
Lúka	Slovakia	B			yes				10000000[m]
Malé Kršteňany	Slovakia	B			yes				10000000[m]
Modrová	Slovakia	B			yes				10000000[m]
Mútnik	Slovakia	B			yes				10000000[m]
Rajec-Šuja	Slovakia	B			yes				10000000[m]
Rajecká Lesná	Slovakia	B			yes				10000000[m]
Stráňavy-Strečno-Ko-sová	Slovakia	B			yes				10000000[m]
Trebejov	Slovakia	B			yes				10000000[m]
Trstín	Slovakia	B			yes				10000000[m]
Hellamaa	Estonia	C	Not exploited		no	917967			917967

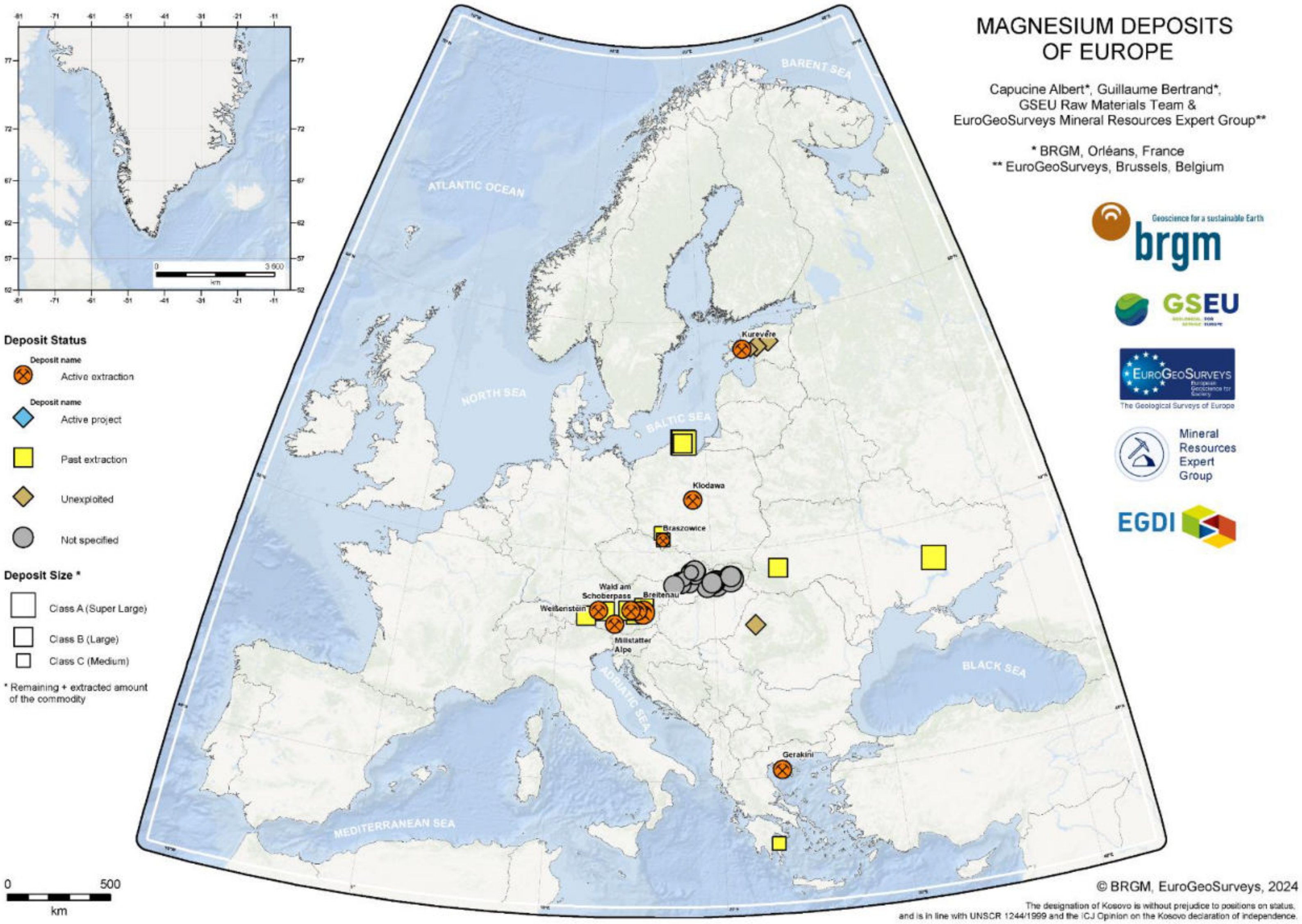
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
						(Mg metal)			(Mg metal)
Fokiano Bay (Arkadia)	Greece	C	Not operating		no	770850 (Mg metal)			770850 (Mg metal)
Tamme	Estonia	C	Not exploited		no	359825 (Mg metal)			359825 (Mg metal)
Wiry	Poland	C	Not operating		no	7016400			7016400
Braszowice	Poland	C	Operating	Magnesite	no	3269000	3269000	66380	3335380
Grochów	Poland	C	Not operating		no	2718000			2718000
Ochtiná	Slovakia	C			yes				1000000[m]
Podrečany	Slovakia	C			yes				1000000[m]
Družstevná pri Hornáde-Malá Vieska	Slovakia	C			yes				1000000[m]
Hubina	Slovakia	C			yes				1000000[m]
Košariská	Slovakia	C			yes				1000000[m]
Kraľovany	Slovakia	C			yes				1000000[m]
Rakša	Slovakia	C			yes				1000000[m]
Rožňové Mitice-Mníchova Lehota	Slovakia	C			yes				1000000[m]
Trenčianske Mitice	Slovakia	C			yes				1000000[m]
Veľká Čierna-Petrová	Slovakia	C			yes				1000000[m]

[m] minimum estimate
* reserves not included in resources

Table 36: *Magnesium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – magnesium contained (tons of X)	Category
Estonia	**29958187** (Mg metal)	2 – mineral resources
Greece	**11215439** ($MgCO_3$) + **770850** (Mg metal)	4 – historical or non-compliant
Poland	**6733000** ($MgCO_3$) **718173400** ($MgCO_3$)	1 – mineral reserves 2 – mineral resources
Ukraine	**105134000** ($MgCO_3$) + **13679291** (Mg metal)	1 – mineral reserves

Figure 20: *Map of magnesium deposits in Europe.*



3.19. Manganese (Mn)

Manganese is found primarily in sedimentary and hydrothermal deposits. In addition to the list below, Ukraine hosts significant manganese resources, but data of they are not available at this stage.

***Table 37:** Main European manganese deposits identified in 2024. Tonnages are in tons of Mn metal.*

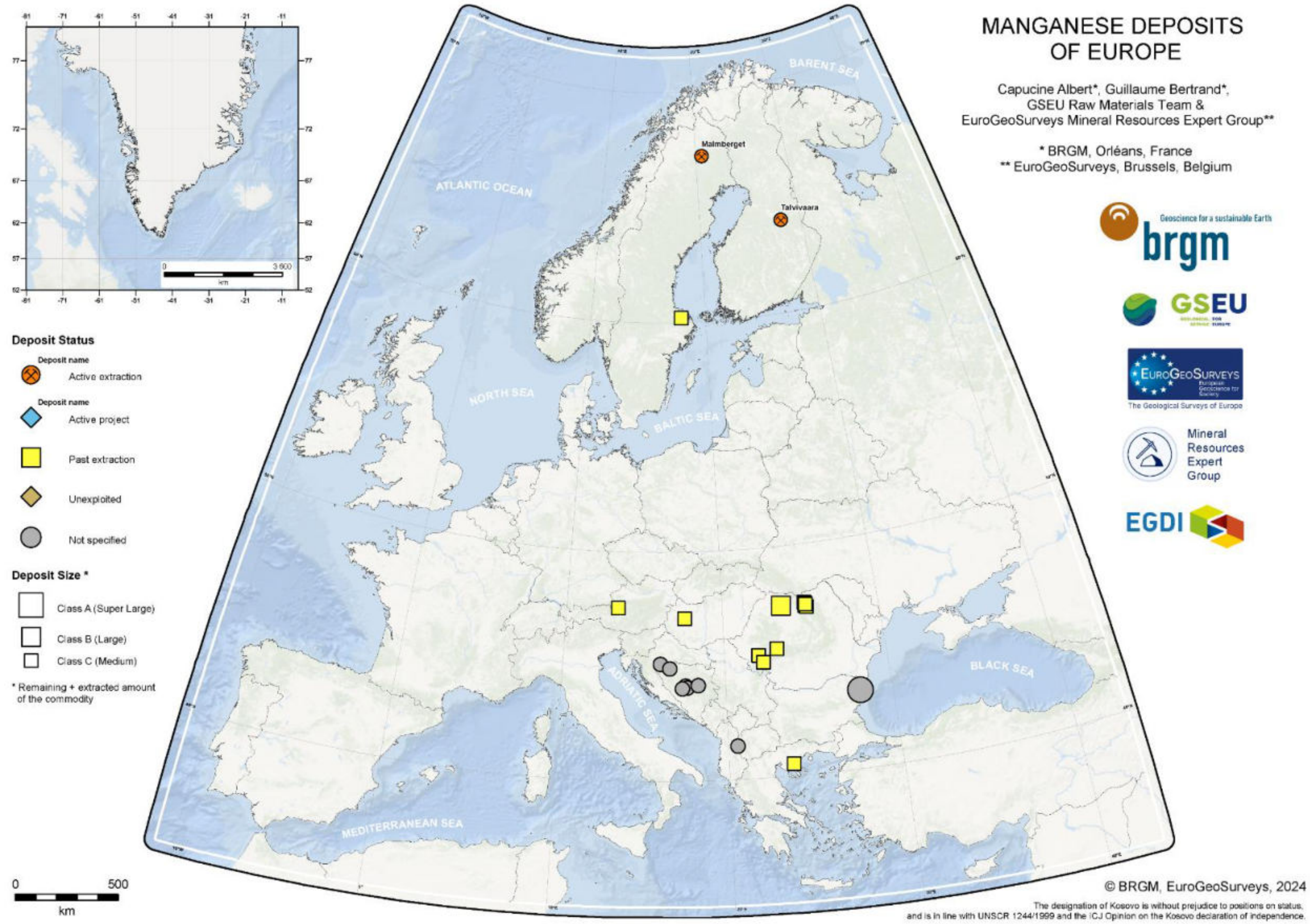
Name	Country	Class	Deposit status	Commodities currently mined	Confi-dential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Obrochishte	Bulgaria	A							100000000[m]
Razoare	Romania	B	Closed		yes				10000000[m]
Úrkút	Hungary	C	Closed		no	5415452		1190000	6605452
Piavitsa-Hunter	Greece	C	Abandoned		no	3570000		340000	3910000
Talvivaara	Finland	C	Operating	Ni, Co	no	3012000			3012000
Malmberget	Sweden	C	Operating	Fe	no			1524000	1524000
Dannemorafältet	Sweden	C	Closed		no	801150		714000	1515150
Delinesti	Romania	C	Closed		no	1040000			1040000
Strubberg	Austria	C	Abandoned		yes				1000000[m]
Popovic Polje	Bosnia & Herze-govina	C							1000000[m]
Radostovo	Bosnia & Herze-govina	C							1000000[m]
Vrnograc	Bosnia & Herze-govina	C							1000000[m]
Cevljanovici	Bosnia & Herze-govina	C							1000000[m]
Ljubija	Bosnia & Herze-govina	C							1000000[m]
Vares	Bosnia & Herze-govina	C							1000000[m]
Stogovo	North Macedonia	C							1000000[m]
Tolovanu	Romania	C	Closed		yes				1000000[m]
Iacobeni	Romania	C	Closed		yes				1000000[m]
Saru-Dornei-Sarisor	Romania	C	Closed		yes				1000000[m]
Dl. Rusului	Romania	C	Closed		yes				1000000[m]
Vacarie	Romania	C	Closed		yes				1000000[m]
Pravat-Batrana	Romania	C	Closed		yes				1000000[m]
Globu Rau	Romania	C	Closed		yes				1000000[m]

[m] minimum estimate

***Table 38:** Manganese resources/reserves from the main deposits in Europe.*

Country	Remaining resources – manganese contained (tons of Mn metal)	Category
Finland	**3012000**	4 – historical or non-compliant
Greece	**3570000**	4 – historical or non-compliant
Hungary	**5415452**	2 – mineral resources
Romania	**1040000**	2 – mineral resources
Sweden	**801150**	2 – mineral resources

***Figure 21:** Map of manganese deposits in Europe.*



3.20. Natural Graphite (C)

The main mineral is graphite, which is composed only of elemental carbon. Three types of natural graphite are commercial products: 1) flake graphite, with important deposits located in Norway and Sweden, 2) amorphous graphite, typically found in low-grade metamorphic rocks in central Europe, and 3) lump and chip crystalline graphite, which is not significant in Europe. For all graphite deposits, it is the flake size and carbon content that determine the value, price and end use of the produced graphite concentrate.

Table 39: *Main European graphite deposits identified in 2024. Tonnages are in tons of graphite.*

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Burtynske	Ukraine	A	Not operating		no	2075100	10683100*		12758200
Zavallivske	Ukraine	B	Care and maintenance		no	7629800	1536000*	2900	9168700
Nunasvaara	Sweden	B	Not exploited		no	5041600	544660*		5586260
Amitsoq	Greenland	B	Under development		no	4704505		1260	4705765
Jalkunen	Sweden	B	Not exploited		no	4693500			4693500
Vikeid	Norway	B	Not exploited		no	3348190			3348190
Bukkemoen	Norway	B	Not exploited		no	3315000			3315000
Balahivske (Pivdenna)	Ukraine	B	Not operating		no	1126800	2145450*		3272250
Niska	Sweden	B	Not exploited		no	3209950			3209950
Instøya	Norway	B	Not exploited		no	1376400			1376400
Smines	Norway	B	Not exploited		no	1341190			1341190
Aitolampi	Finland	B	Not exploited		no	1276794			1276794
Vardfjellet	Norway	B	Not exploited		no	1126080			1126080
Trandorf	Austria	B	Abandoned		yes				1000000[m]
Zettlitz	Austria	B	Abandoned		yes				1000000[m]
Kolodeje nad Luznici-Hosty	Czechia	B			yes				1000000[m]
Blizna-Cerna v Posumavi	Czechia	B			yes				1000000[m]
Český Krumlov	Czechia	B			yes				1000000[m]
Villar	Italy	B	Pending approval		yes				1000000[m]
Kropfmühl	Germany	C	Operating	Graphite	no	820000		75000	895000
Skaland	Norway	C	Closed		no			800000	800000
Eqalussuit	Greenland	C	Not operating		no	793800			793800
Grønjorda	Norway	C	Not exploited		no	714600			714600
Petrivske	Ukraine	C	Not operating		no		655000*		655000
Trælen	Norway	C	Operating	Graphite	no	434000		142221	576221
Mattsmyra	Sweden	C	Not exploited		no	550500			550500
Rendalsvik	Norway	C	Abandoned		no	510000			510000
Møkland	Norway	C	Not exploited		no	448800			448800
Jennestad	Norway	C	Not exploited		no	330240			330240
Raitajärvi	Sweden	C	Not exploited		no	305300			305300
Kringeltjärn	Sweden	C	Care and maintenance		no	270000			270000
Mariupolske	Ukraine	C	Not operating		no		225000*		225000
Troitske	Ukraine	C	Not operating		no		224000*		224000
Gropabo	Sweden	C	Not exploited		no	182520			182520
Grunnvåg	Norway	C	Not exploited		no	143000			143000

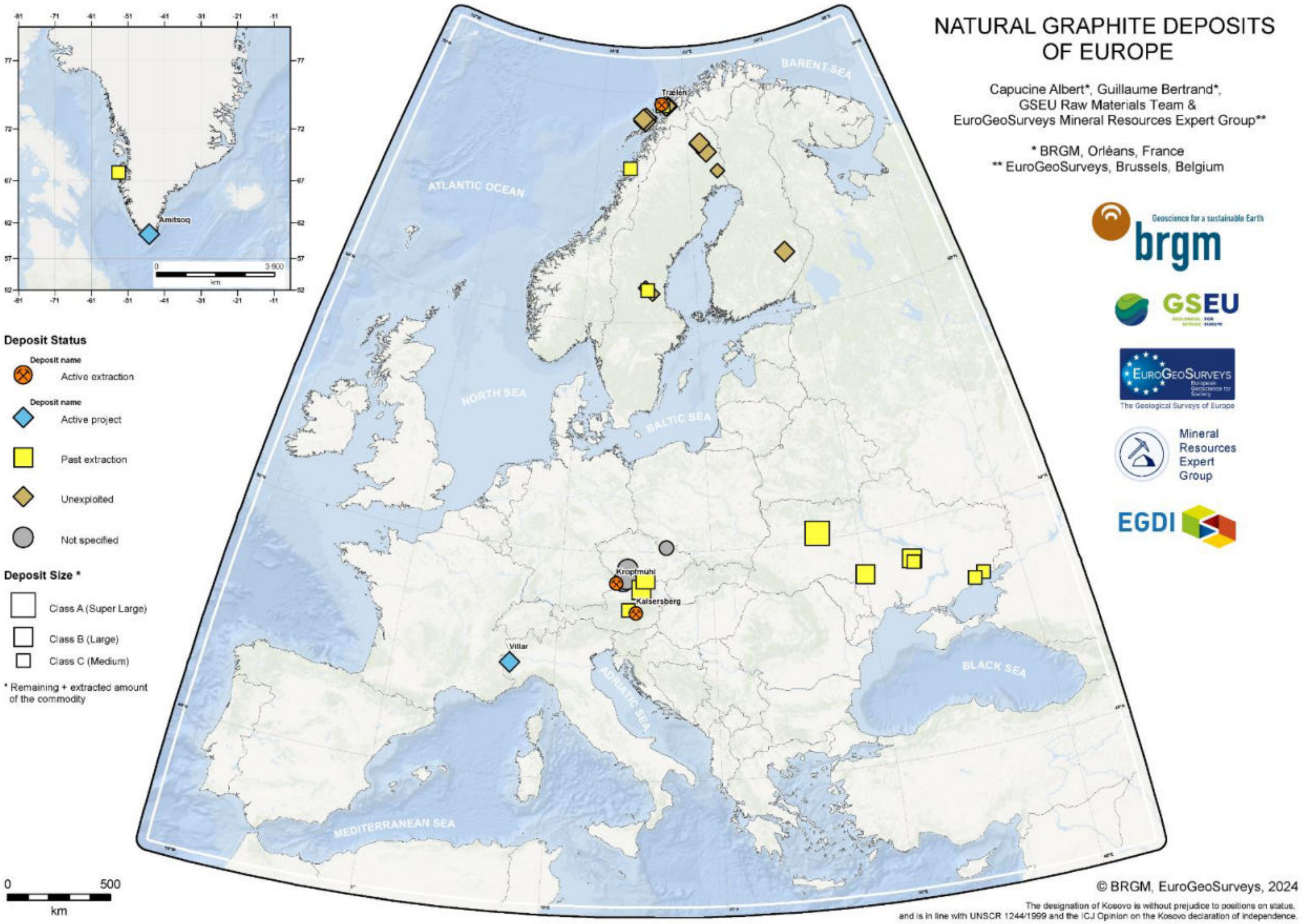
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Månsberg	Sweden	C	Not exploited		no	141600			141600
Hesten	Norway	C	Not exploited		no	112000			112000
Sunk/Trieben	Austria	C	Abandoned		yes				100000[m]
Kaisersberg	Austria	C	Operating	Graphite	yes				100000[m]
Velke Vrbno-Konstantin	Czechia	C			yes				100000[m]

[m] minimum estimate
* reserves not included in resources

Table 40: *Natural graphite resources/reserves from the main deposits in Europe.*

Country	Remaining resources – graphite contained (tons)	Category
Finland	**1276794**	2 – mineral resources
Germany	**820000**	4 – historical or non-compliant
Greenland	**4704505** **793800**	2 – mineral resources 4 – historical or non-compliant
Norway	**434000** **12765500**	2 – mineral resources 4 – historical or non-compliant
Sweden	**544660** **14253370** **141600**	1 – mineral reserves 2 – mineral resources 4 – historical or non-compliant
Ukraine	**15468550** **3201900** **7629800**	1 – mineral reserves 2 – mineral resources 3 – compliant historical

__Figure 22:__ Map of natural graphite deposits in Europe.



3.21. Nickel (Ni)

Nickel is mined from sulphide ores where it occurs as pentlandite ($(Fe,Ni)_9S_8$), or laterite ores where it occurs as garnierite and nickeliferous limonite. It is very often associated with chromium and cobalt, with which it shares chemical affinities, as well as with iron, manganese and magnesium.

Table 41: *Main European nickel deposits identified in 2024. Tonnages are in tons of Ni metal.*

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Talvivaara	Finland	A	Operating	Ni, Co	no	2332000	1313000*	263343	3908343
Evia	Greece	B	Not operating		no	1211800			1211800
Myrviken	Sweden	B	Not exploited		no	1041080			1041080
Bitinckë	Albania	B	Operating intermittently	Ni	no	885808		14863	900671
Hotinvaara	Finland	B	Not exploited		no	844360			844360
Kevitsa	Finland	B	Operating	Ni, Cu, Co, Pt, Pd, Au	no	393388	167484*	124613	685485
Häggån	Sweden	B	Not exploited		no	681700			681700
Vardiste	Bosnia & Herzegovina	B							500000[m]
Crna Tumba	North Macedonia	B							500000[m]
Truall Surroj	Albania	C	Operating	Ni	no	483176		3983	487159
Rzanovo	North Macedonia	C	Operating	Ni		445024			445024
Sakatti	Finland	C	Not exploited		no	425796			425796
Kapshticë	Albania	C	Operating intermittently	Ni	no	378680		704	379384
Aghios Ioannis-Marmeiko (Lokris)	Greece	C	Not operating		no	377300			377300
Prrenjas	Albania	C	Not operating		no	312162		26938	339100
Enora	Germany	C	Not exploited		no	294500			294500
Rönnbäcksnäset	Sweden	C	Not exploited		no	280000			280000
Sundsberget	Sweden	C	Not exploited		no	252000			252000
Gllavica	Kosovo[5]	C	Operating	Ni	no	96720	0	99750	196470
Ruossakero	Finland	C	Not exploited		no	168400			168400
Szklary	Poland	C	Not operating		no	155000			155000
Ahmavaara	Finland	C	Not exploited		no	129561			129561
Hitura	Finland	C	Closed		no	23978		92623	116601
Njeretjakke	Sweden	C	Not exploited		no	107240			107240
Cervenakë	Albania	C	Operating	Ni, Fe	no	89034		15610	104644
New Copper District	Poland	C	Operating	Cu, Ag, Pb, Ni, Re, Au	no	100740		830	101570
Vaaralampi	Finland	C	Not exploited		no	99200			99200
Chervoniy Yar	Ukraine	C	Not operating		no	88800			88800
Ieropigi	Greece	C	Not operating		no	87300			87300
Kotalahti	Finland	C	Closed		no			82080	82080
Kaukua	Finland	C	Not exploited		no	79860			79860
Devladivske	Ukraine	C	Not operating		no		78600*		78600
Vinberget	Sweden	C	Not exploited		no	78000			78000
Bruvann	Norway	C	Abandoned		no	32940		44392	77332
Rörmyrberget	Sweden	C	Not exploited		no	69920			69920
Pappilanmäki	Finland	C	Not exploited		no	65437			65437

[5] This designation (of Kosovo) is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total en-dowment (t)
Derenyukhynske	Ukraine	C	Not operating		no		9800*	54200	64000
Stormi	Finland	C	Closed		no	7040		51496	58536
Lypovenkivske	Ukraine	C	Not operating		no		39000*	18300	57300
Lokridha	Greece	C	Not operating		no	52000		3900	55900
Enonkoski	Finland	C	Closed		no	4830		50487	55317
Ertelien	Norway	C	Closed		no	49700		2324	52024
Tarnavatske	Ukraine	C	Not operating		no		51700*		51700
Siika-Kämä Reef	Finland	C	Not exploited		no	40508			40508
Arthrath	UK	C			no	35700			35700
Aguablanca	Spain	C	Under devel-opment		no	34846	31577		34846
Konttijärvi	Finland	C	Not exploited		no	34610			34610
Bushtricë	Albania	C	Operating in-termittently	Ni	no	13096		20061	33157
Rodburn	UK	C			no	30960			30960
Haukiaho	Finland	C	Not exploited		no	26460			26460
Vaara	Finland	C	Not exploited		no	26043			26043
Älgliden	Sweden	C	Not exploited		no	26000			26000
Hautalampi	Finland	C	Not exploited		no	10308	13463*		23772
Kylylahti	Finland	C	Closed		no	19212		3138	22350
Dalen	Norway	C	Not exploited		no	21840			21840
Vatera-Lesvos	Greece	C	Not operating		no	21000			21000
Flåt/Evje	Norway	C	Abandoned		no			20250	20250
Groot	North Macedonia	C							20000[m]

[m] minimum estimate
* reserves not included in resources

Table 42: *Nickel resources/reserves from the main deposits in Europe.*

Country	Remaining resources – nickel contained (tons of Ni metal)	Category
Albania	**2161956**	2 – mineral resources
Finland	**1493948** **4676141** **50020** **4830**	1 – mineral reserves 2 – mineral resources 3 – compliant historical 4 – historical or non-compliant
Germany	**294500**	4 – historical or non-compliant
Greece	**1749400**	4 – historical or non-compliant
Kosovo[6]	**96720**	4 – historical or non-compliant
North Macedonia	**445024**	4 – historical or non-compliant
Norway	**104480**	2 – mineral resources
Poland	**255740**	2 – mineral resources
Spain	**31577** **3268**	1 – mineral reserves 2 – mineral resources
Sweden	**2402700** **133240**	2 – mineral resources 4 – historical or non-compliant
UK	**66660**	4 – historical or non-compliant
Ukraine	**179100** **88800**	1 – mineral reserves 2 – mineral resources

[6] This designation (of Kosovo) is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

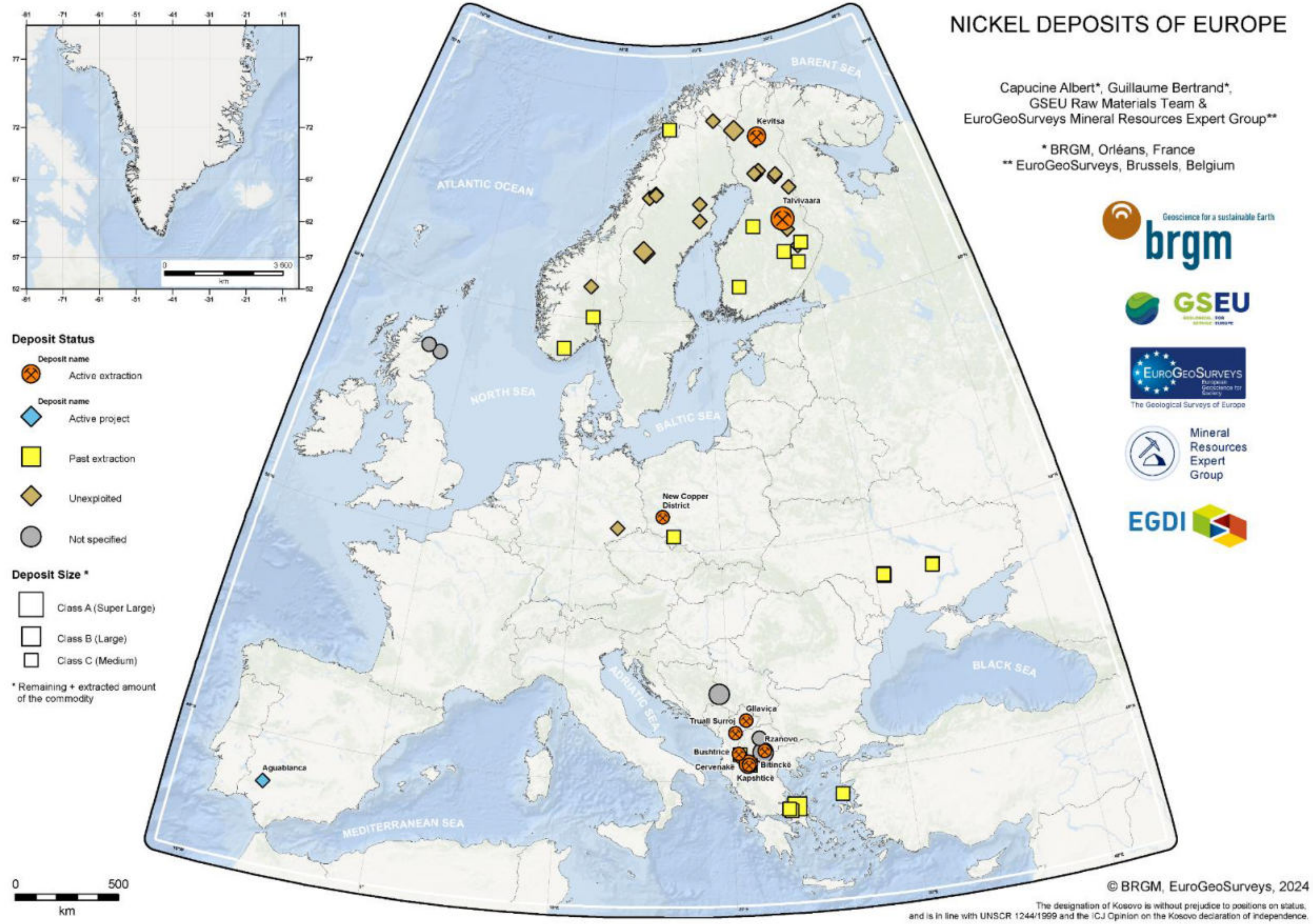


Figure 23: *Map of nickel deposits in Europe.*

3.22. Niobium (Nb)

The main commercial sources of niobium are Nb-oxides (columbite-tantalite and pyrochlore) in carbonatite and granite-associated deposits.

Table 43: *Main European niobium deposits identified in 2024. Tonnages are in tons of Nb_2O_5.*

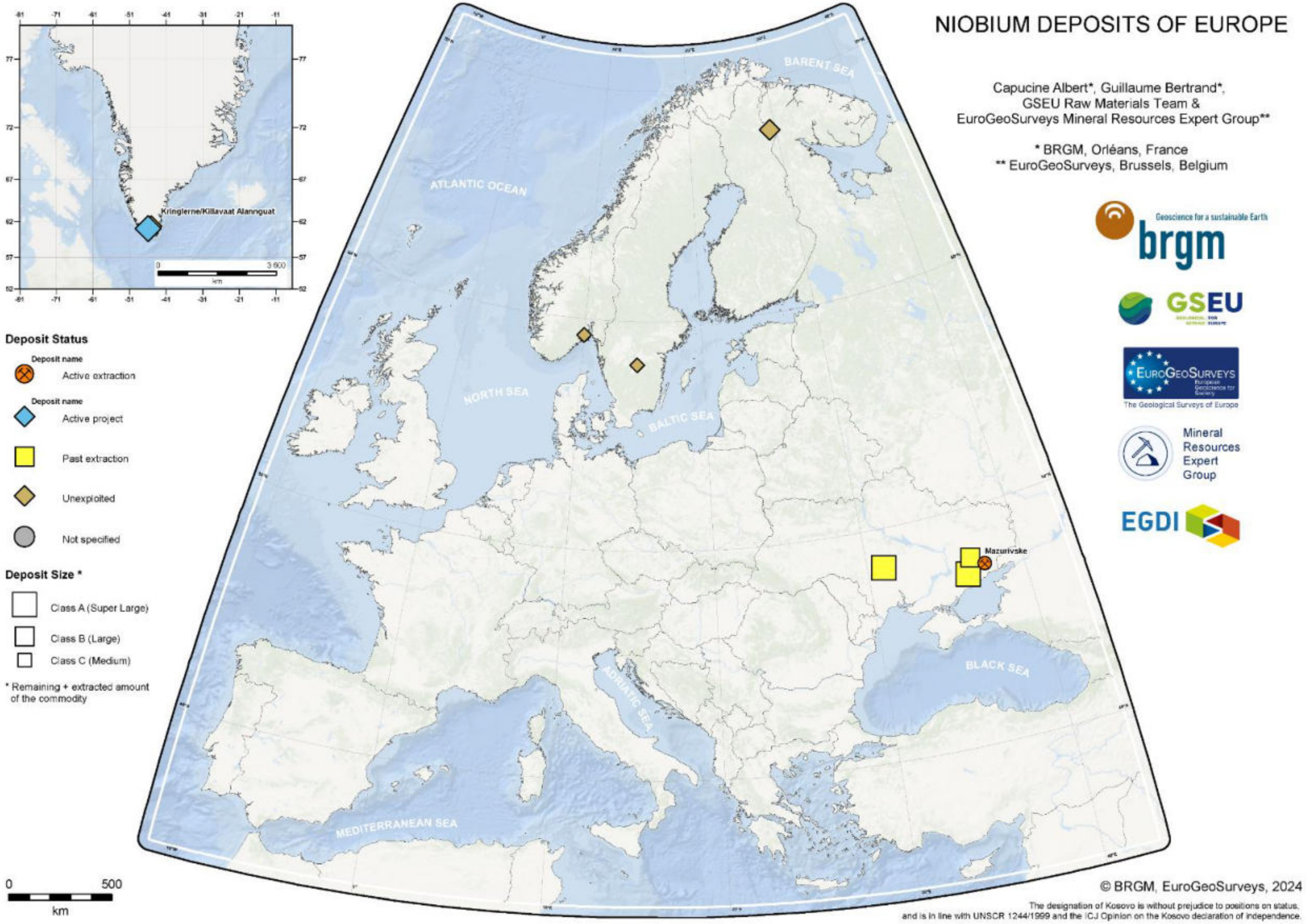
Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Kringlerne/Killavaat Alannguat	Greenland	A	Under devel-opment		no	7738147			7738147
Dobra	Ukraine	A	Not operating		yes				1000000[m]
Novopoltavske	Ukraine	A	Not operating		yes				1000000[m]
Motzfeldt	Greenland	B	Not exploited		no	632281			632281
Sokli	Finland	B	Not exploited		no	161910			161910
Shevchenkivske	Ukraine	B	Not operating		yes				100000[m]
Norra Kärr	Sweden	C	Not exploited		no	55000			55000
Sæteråsen	Norway	C	Not exploited		no	28038			28038
Mazurivske	Ukraine	C	Operating	Nb, Zr	yes				10000[m]

[m] minimum estimate

Table 44: *Niobium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – niobium contained (tons of Nb_2O_5)	Category
Finland	**161910**	4 – historical or non-compliant
Greenland	**8370428**	4 – historical or non-compliant
Norway	**28038**	4 – historical or non-compliant
Sweden	**55000**	2 – mineral resources

Figure 24: *Map of niobium deposits in Europe.*



3.23. Platinum Group Metals (Pt, Pd, Rh, Ru, Ir, Os)

Platinum group metals include platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), iridium (Ir) and osmium (Os). Platinum and palladium are most common and their production is tenfold compared to other PGM. These metals are typically found in sulfide ores in mafic and ultramafic igneous rocks. Finland is notable for hosting small PGM-bearing deposits, particularly in the Outokumpu and Kemi regions.

Table 45: *Main European PGM deposits identified in 2024. Tonnages are in tons of PGM metal.*

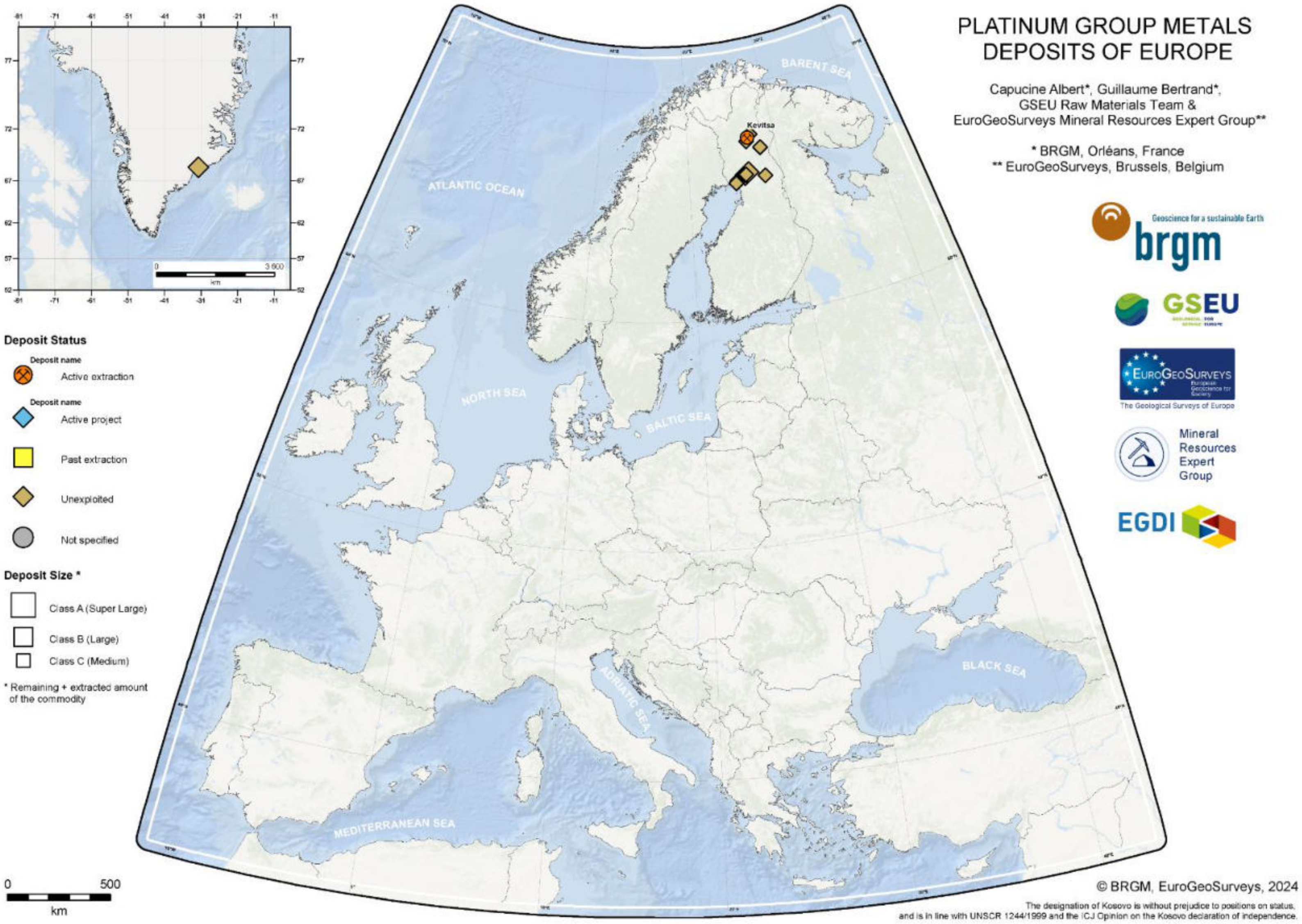
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Skaergaard	Greenland	B	Not exploited		no	576			576
Ahmavaara	Finland	B	Not exploited		no	187			187
Siika-Kämä Reef	Finland	B	Not exploited		no	154			154
Konttijärvi	Finland	C	Not exploited		no	92			92
Kevitsa	Finland	C	Operating	Ni, Cu, Co, Pt, Pd, Au	no	37	25*	24	86
Koitelainen UC	Finland	C	Not exploited		no	77			77
Sompujärvi Reef	Finland	C	Not exploited		no	59			59
Kaukua	Finland	C	Not exploited		no	52			52
Sakatti	Finland	C	Not exploited		no	50			50
Yli-Portimojärvi	Finland	C	Not exploited		no	39			39
Paasivaara	Finland	C	Not exploited		no	33			33
Vaaralampi	Finland	C	Not exploited		no	30			30
Ala-Penikkavaara	Finland	C	Not exploited		no	27			27
Akanvaara UC	Finland	C	Not exploited		no	17			17
Akanvaara LC	Finland	C	Not exploited		no	16			16

* reserves not included in resources

Table 46: *PGM resources/reserves from the main deposits in Europe.*

Country	Remaining resources – PGM contained (tons of PGM)	Category
Finland	**25** **602** **268**	1 – mineral reserves 2 – mineral resources 4 – historical or non-compliant
Greenland	**576**	2 – mineral resources

__Figure 25:__ Map of PGM deposits in Europe.



3.24. Phosphate Rock/Phosphorous (P)

Phosphate rock and phosphorus are sourced from the same deposit types and the latter results from processing the former. In Europe, phosphorus mostly occurs in igneous deposits where it is hosted in the mineral apatite (calcium phosphate), particularly in the Scandinavian region.

Table 47: *Main European phosphate rock/phosphorous deposits identified in 2024. Tonnages are in tons of* P_2O_5.

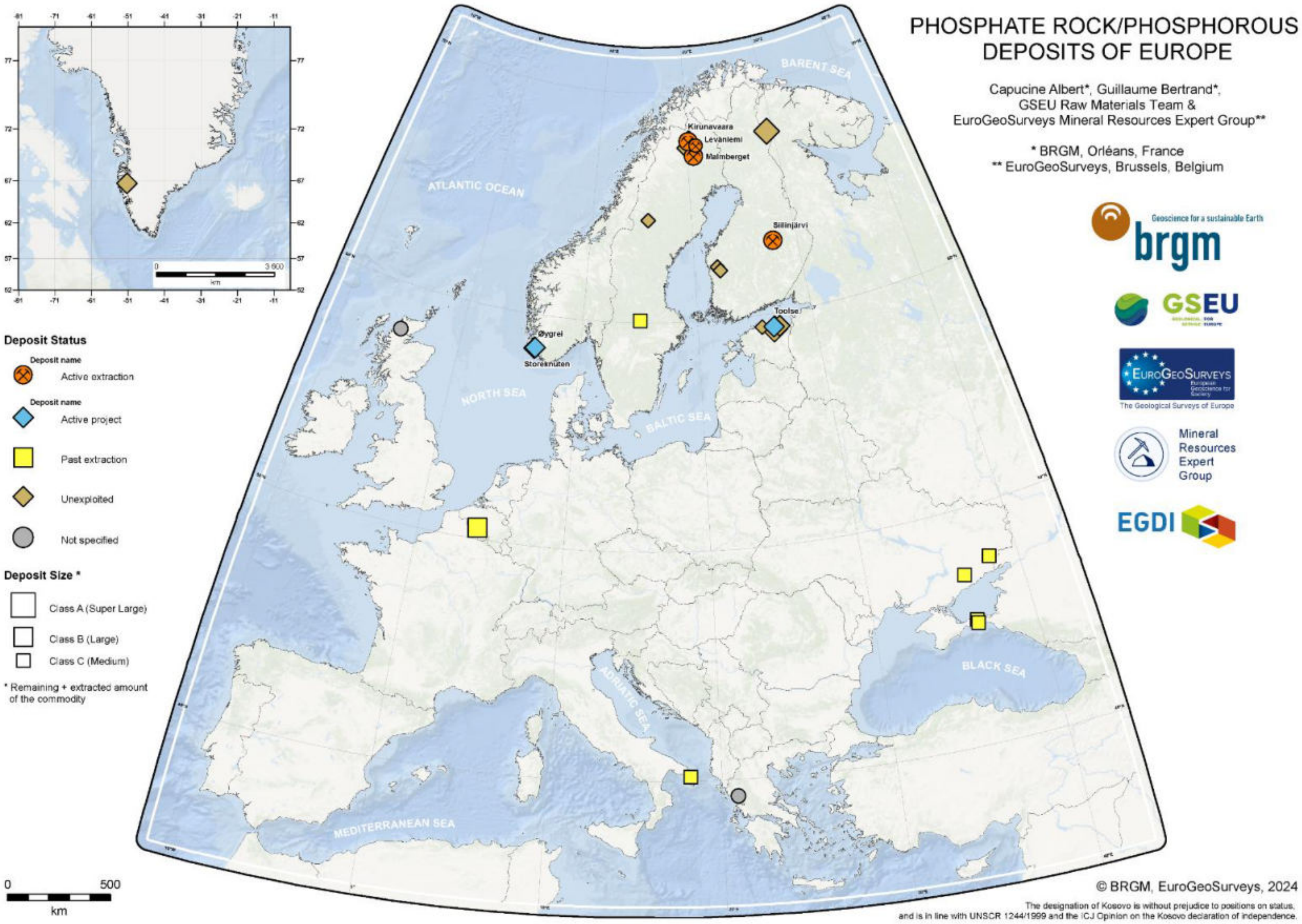
Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Sokli	Finland	A	Not exploited		no	452630970			452630970
Rakvere	Estonia	A	Not exploited		no	271366620		0	271366620
Storeknuten	Norway	B	Feasibility		no	81075200			81075200
Toolse	Estonia	B	Feasibility		no	64389900		0	64389900
Per Geijer	Sweden	B	Not exploited		no	50825855			50825855
Siilinjärvi	Finland	B	Operating	P	no	37252712		13168910	50421622
Hainaut	Belgium	B	Closed		no	48000000		700000	48700000
Kirunavaara	Sweden	B	Operating	Fe	no	11788907		24502933	36291840
Malmberget	Sweden	B	Operating	Fe	no	27021172		6806969	33828141
Sarfartoq	Greenland	B	Not exploited		no	26252627			26252627
Aseri	Estonia	B	Not exploited		no	24921680		0	24921680
Øygrei	Norway	B	Feasibility		no	21603200			21603200
Leväniemi	Sweden	C	Operating	Fe	no	16002701		978972	16981673
Osykivske	Ukraine	C	Not operating		no	10800000			10800000
Tåsjö	Sweden	C	Not exploited		no	5999409			5999409
Grängesberg mining district	Sweden	C	Closed		no	2990630		2678055	5668685
Perämaa	Finland	C	Not exploited		no	5400000			5400000
Lumikangas	Finland	C	Not exploited		no	5060000			5060000
Drimonas-Preveza	Greece	C			no	5000000			5000000
Kamysh-Burunske	Ukraine	C	Not operating		no		4852000*		4852000
Salentino Peninsula	Italy	C	Abandoned		no	4500000			4500000
Novopoltavske	Ukraine	C	Not operating		no		4323813*		4323813
Tsitre	Estonia	C	Not exploited		no	3778380		0	3778380
Kyz-Aulske	Ukraine	C	Not operating		no		2897000*		2897000
Pattok	Sweden	C	Not exploited		no	2802718			2802718
Loch Borralan	UK	C			no	2000000			2000000

* reserves not included in resources

Table 48: *Phosphorous resources/reserves from the main deposits in Europe.*

Country	Remaining resources – phosphorous contained (tons of P_2O_5)	Category
Belgium	**48000000**	4 – historical or non-compliant
Estonia	**364456580**	2 – mineral resources
Finland	**37252712** **452630970** **10460000**	2 – mineral resources 3 – compliant historical 4 – historical or non-compliant
Greece	**5000000**	4 – historical or non-compliant
Greenland	**26252627**	4 – historical or non-compliant
Italy	**4500000**	4 – historical or non-compliant
Norway	**102678400**	2 – mineral resources
Sweden	**111431983** **5999409**	2 – mineral resources 4 – historical or non-compliant
UK	**2000000**	4 – historical or non-compliant
Ukraine	**12072813** **10800000**	1 – mineral reserves 3 – compliant historical

Figure 26: *Map of phosphate rock/phosphorous deposits in Europe.*



3.25. Rare Earth Elements (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Y)

The rare earth elements (REE) comprise yttrium (Y) and the Lanthanide Group of the periodic table of elements (lanthanum to lutetium). These are commonly separated into two groups, the heavy rare earth elements (HREE – Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, together with Y), and the light rare earth elements (LREE – La, Ce, Pr, Nd, and Sm). Typically, all aforementioned elements occur in all REE-bearing deposits, but in very variable proportions depending on geological processes. Most of the global production has been extracted from REE-bearing carbonate (e.g. bastnäsite) and phosphate (e.g. monazite) ores. In Europe, REE deposits are relatively modest, but some significant exploration efforts in countries like Sweden and Finland have identified bastnäsite and monazite deposits.

Table 49: *Main European REE deposits identified in 2024. Tonnages are in tons of REE_2O_3.*

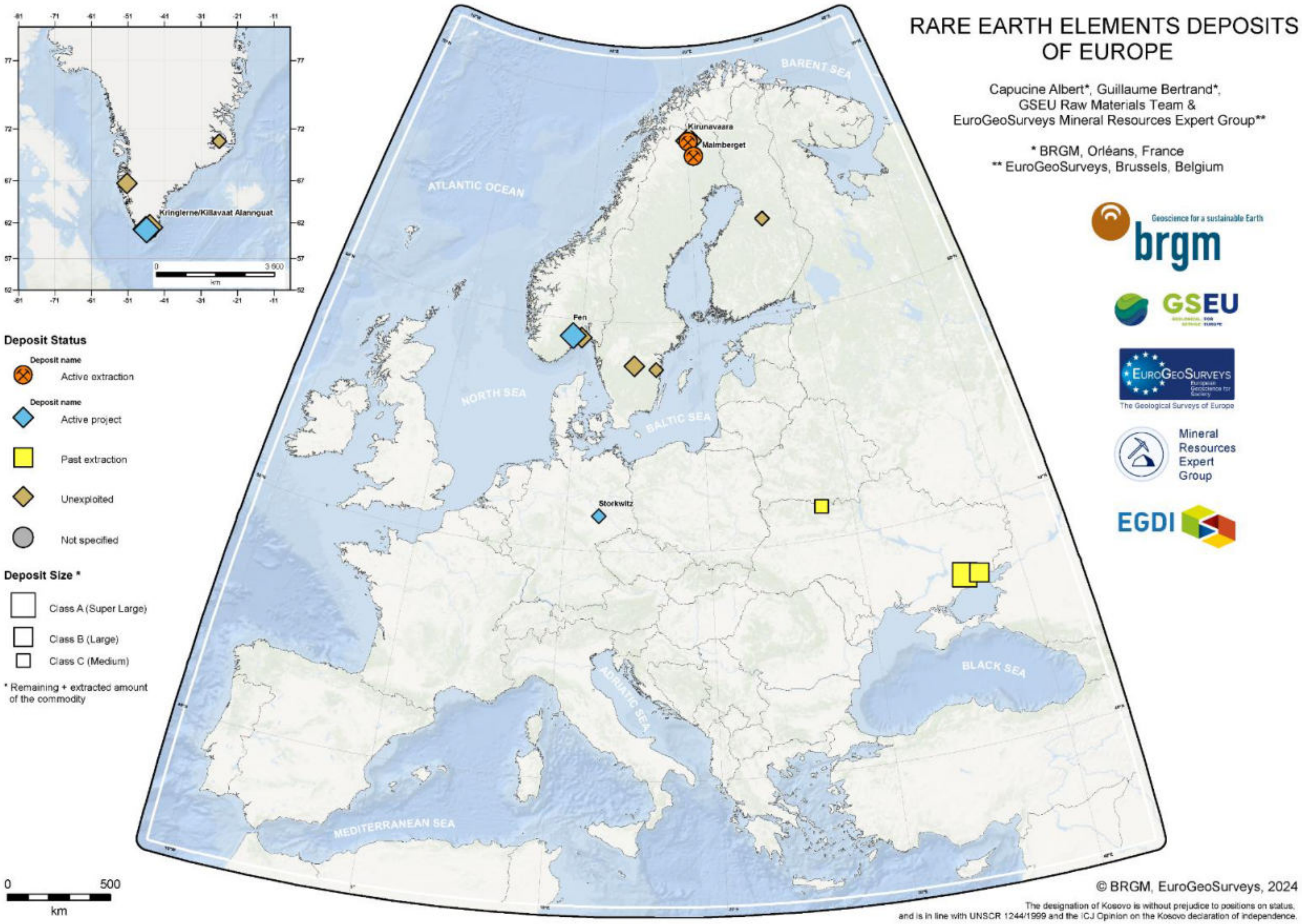
Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Kringlerne/Killavaat Alannguat	Greenland	A	Under devel-opment		no	28000224			28000224
Kvanefjeld/Kuannersuit	Greenland	A	Not exploited		no	10227640			10227640
Fen	Norway	A	Feasibility		no	10000000			10000000
Motzfeldt	Greenland	A	Not exploited		no	3558168			3558168
Novopoltavske	Ukraine	A	Not operating		no		2212000*		2212000
Per Geijer	Sweden	A	Not exploited		no	1739920			1739920
Azovske	Ukraine	B	Not operating		no	708480			708480
Norra Kärr	Sweden	B	Not exploited		no	550000			550000
Malmberget	Sweden	B	Operating	Fe	no	447260			447260
Kirunavaara	Sweden	B	Operating	Fe	no	255780			255780
Sarfartoq	Greenland	B	Not exploited		no	146513			146513
Kodal	Norway	B	Not exploited		no	101500			101500
Olserum	Sweden	C	Not exploited		no	47970			47970
Kontioaho	Finland	C	Not exploited		no	45294			45294
Milne Land	Greenland	C	Not exploited		no	41861			41861
Storkwitz	Germany	C	Feasibility		no	38000			38000
Yastrubetske	Ukraine	C	Not operating		no		21750*		21750
Katajakangas	Finland	C	Not exploited		no	11049			11049

* reserves not included in resources

Table 50: *REE resources/reserves from the main deposits in Europe.*

Country	Remaining resources – REE contained (tons of REE_2O_3)	Category
Finland	**56343**	4 – historical or non-compliant
Germany	**38000**	4 – historical or non-compliant
Greenland	**10374153** **31600253**	2 – mineral resources 4 – historical or non-compliant
Norway	**10101500**	2 – mineral resources
Sweden	**3040930**	2 – mineral resources
Ukraine	**2233750** **708480**	1 – mineral reserves 3 – compliant historical

Figure 27: *Map of REE deposits in Europe.*



3.26. Scandium (Sc)

Scandium is a rare metal typically found in small quantities within scandium-bearing minerals such as thortveitite and bazzite, as well as in some niobium and tantalum deposits. It is usually recovered as a by-product from bauxite ores, and in some cases from uranium deposits. It has strong chemical affinities with Rare Earth Elements.

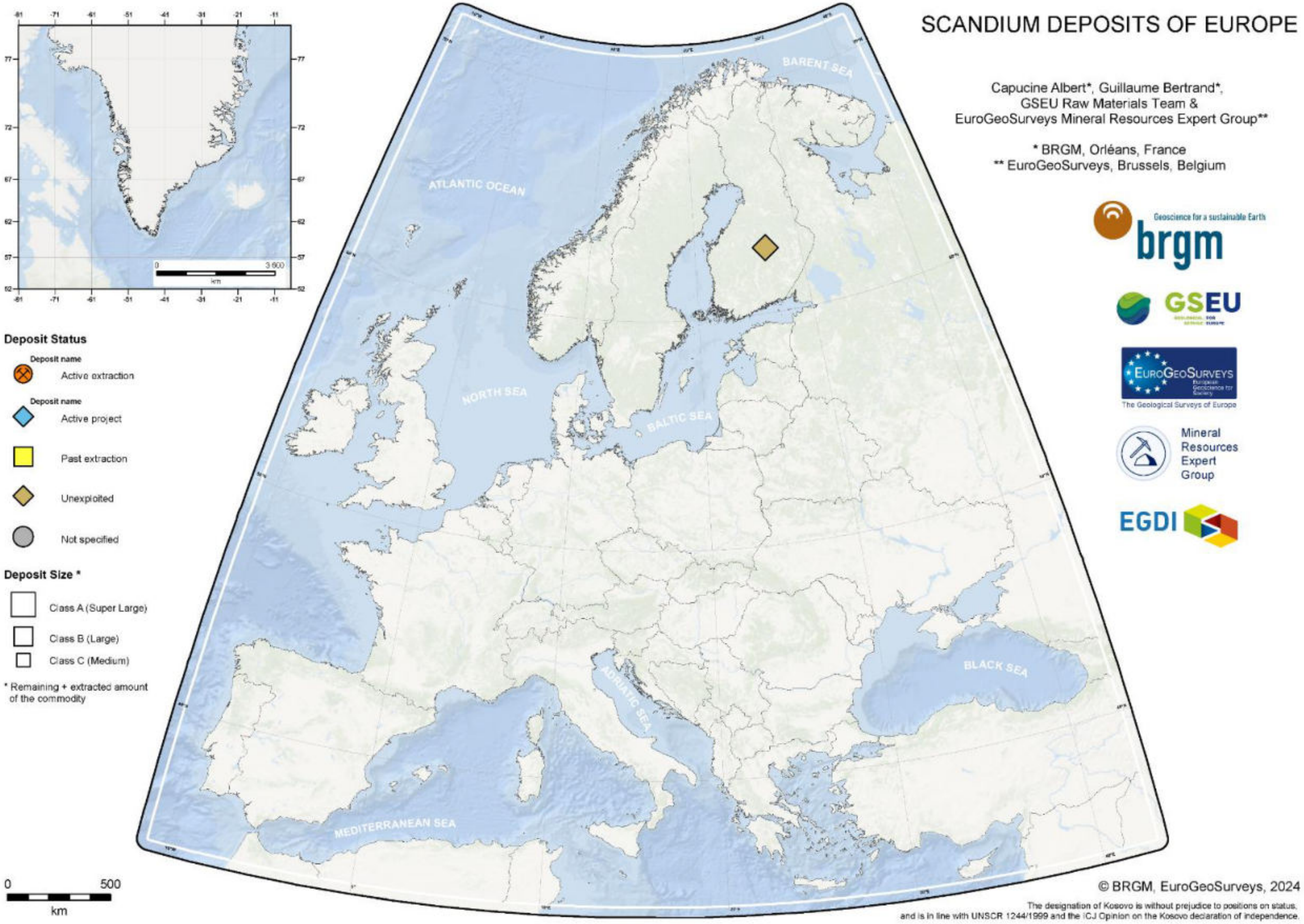
***Table 51:** Main European scandium deposits identified in 2024. Tonnages are in tons of Sc metal.*

Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Kiviniemi	Finland	A	Not exploited		no	2180			2180

***Table 52:** Scandium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – scandium contained (tons of Sc metal)	Category
Finland	**2180**	4 – historical or non-compliant

Figure 28: *Map of scandium deposits in Europe.*



3.27. Silicon metal (Si)

Silicon metal does not occur as a pure metal in nature, but is produced from pure quartz (SiO_2) in dedicated smelters. The production of silicon metal is very energy demanding, and quartz materials need to fulfil strict criteria for purity to be considered metallurgical grade. Moreover, quartz resources are also used for other purposes in larger tonnages than what is used for silicon metal production. Figures for global production are thus uncertain. Resources of silicon metal of > 99.8% purity are not known at this stage.

3.28. Strontium (Sr)

Celestite ($SrSO_4$) and strontianite ($SrCO_3$) are the only commercial sources of strontium. This commodity is mostly recovered from evaporite deposits and, more rarely, from hydrothermal veins where it can accompany fluorite, baryte, lead, and zinc sulphides. In Europe, significant strontium resources are found in Spain, where it is primarily extracted from celestite.

Table 53: *Main European strontium deposits identified in 2024. Tonnages are in tons of* $SrSO_4$*.*

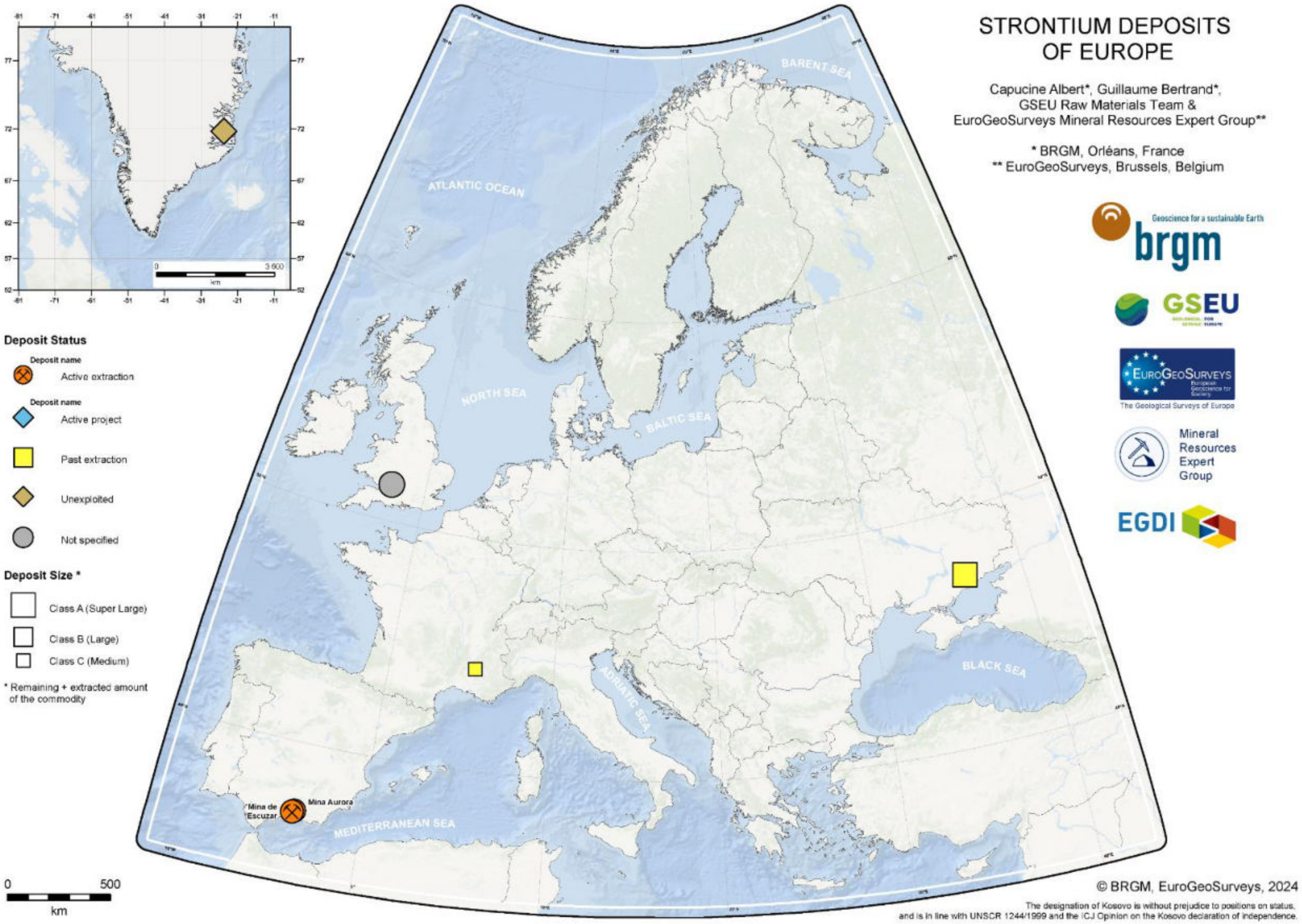
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Karstryggen	Greenland	A	Not exploited		no	20621069			20621069
Yate	UK	A			no	16268000			16268000
Mina de Escuzar	Spain	A	Operating	Celestite	no	4000000		1042000	5042000
Novopoltavske	Ukraine	A	Not operating		no		1687643*		1687643
Mina Aurora	Spain	A	Operating	Celestite	no	1000000		50000	1050000
Condorcet	France	C	Historic		no			60000	60000

* reserves not included in resources

Table 54: *Strontium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – strontium contained (tons of $SrSO_4$)	Category
Greenland	**20621069**	4 – historical or non-compliant
Spain	**5000000**	4 – historical or non-compliant
UK	**16268000**	4 – historical or non-compliant
Ukraine	**1687643**	1 – mineral reserves

Figure 29: *Map of strontium deposits in Europe.*



3.29. Tantalum (Ta)

Tantalum is a rare metal primarily found in the form of tantalite and columbite ores (“coltan”). These ore minerals are commonly associated with granite and pegmatite deposits, as well as some carbonatite deposits. Tantalum is often extracted alongside niobium in these deposits, or as co-product of tin production.

Table 55: *Main European tantalum deposits identified in 2024. Tonnages are in tons of Ta_2O_5.*

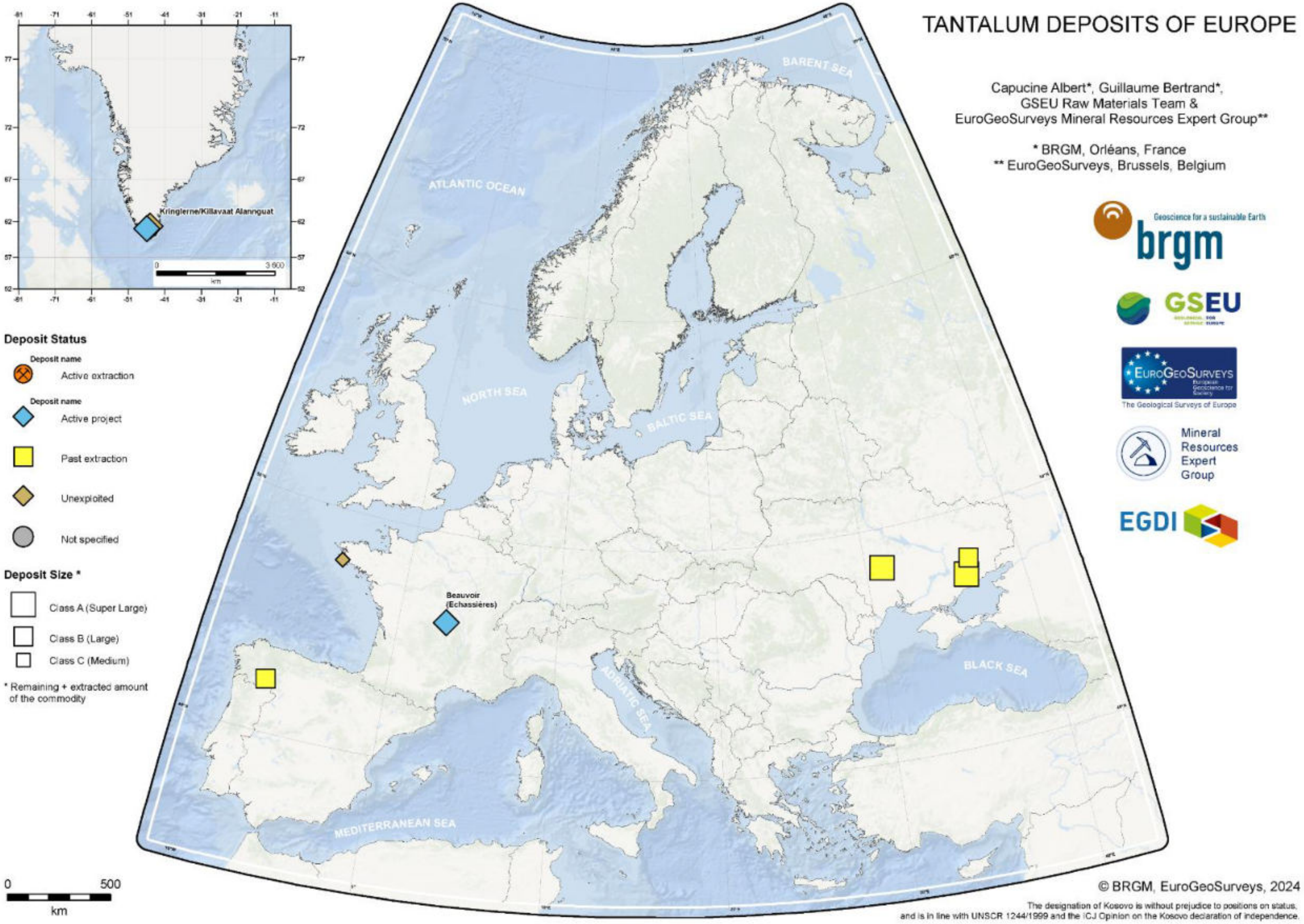
Name	Country	Class	Deposit status	Commodities currently mined	Confidential	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Kringlerne/Killavaat Alannguat	Greenland	A	Under development		no	1076400			1076400
Motzfeldt	Greenland	A	Not exploited		no	41517			41517
Beauvoir (Echassières)	France	A	Under development		no	28574			28574
Dobra	Ukraine	A	Not operating		yes				25000^m
Novopoltavske	Ukraine	A	Not operating		yes				25000^m
Penouta	Spain	B	Not operating		no	11152			11152
Shevchenkivske	Ukraine	B	Not operating		yes				2000^m
Tréguennec-Prat-ar-Hastel	France	C	Not exploited		no	1600			1600

^{m} minimum estimate

Table 56: *Tantalum resources/reserves from the main deposits in Europe.*

Country	Remaining resources – tantalum contained (tons of Ta_2O_5)	Category
France	**30174**	4 – historical or non-compliant
Greenland	**1117917**	4 – historical or non-compliant
Spain	**11152**	2 – mineral resources

Figure 30: Map of tantalum deposits in Europe.



3.30. Titanium metal (Ti)

The mineral ilmenite (iron-titanium oxide, $FeTiO_2$) accounts for about 89% of the world's consumption of titanium, the rest comes from the minerals rutile and anatase (both TiO_2) (Eilu et al., 2021). The end-user product is titanium oxide (TiO_2). Only a small fraction (< 10%) of mined titanium minerals worldwide ends up as titanium metal. Only titanium metal of metallurgical grade is considered critical.

Table 57: *Main European titanium deposits identified in 2024. Unless stated otherwise, tonnages are in tons of TiO_2.*

Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Storeknuten	Norway	A	Feasibility		no	143781800 (t of ilmenite)			143781800 (t of ilmenite)
Tellnes	Norway	A	Operating	Ti	no	102600000 (t of ilmenite)		23866700 (t of ilmenite)	126466700 (t of ilmenite)
Øygrei	Norway	A	Feasibility		no	61041600 (t of ilmenite)			61041600 (t of ilmenite)
Engebøfjellet	Norway	A	Construction		no	13583700 (t of rutile)			13583700 (t of rutile)
Piampaludo	Italy	A	Pending ap-proval		no		9000000* (t of rutile)		9000000 (t of rutile)
Skaergaard	Greenland	B	Not exploited		no	8111860			8111860
Isortoq	Greenland	B	Not exploited		no	7662700			7662700
Ødegårdens Verk	Norway	A	Abandoned		no	3000000 (t of rutile)			3000000 (t of rutile)
Naustdal	Norway	A	Historic		no	3000000 (t of rutile)			3000000 (t of rutile)
Skeipstad	Norway	B	Feasibility		no	19910400 (t of ilmenite)			19910400 (t of ilmenite)
Routivare	Sweden	B	Not exploited		no	13311438			13311438
Storgangen	Norway	B	Abandoned		no	10800000 (t of ilmenite)		1800000 (t of ilmenite)	12600000 (t of ilmenite)
Lumikangas	Finland	B	Not exploited		no	10742564			10742564
Perämaa	Finland	B	Not exploited		no	10675840			10675840
Smålands Taberg	Sweden	B	Closed		no	7506450		76566	7583016
Otanmäki	Finland	B	Closed		no	1774858		3209040	4983898
Kodal	Norway	B	Not exploited		no	4690000 (t of ilmenite)			4690000 (t of ilmenite)
Koivusaarenneva	Finland	B	Not exploited		no	4522191			4522191
Moriusaq	Greenland	B	Not exploited		no	3401700			3401700
Lemnenske	Ukraine	B	Not operating		yes				2000000[m]
Voskresenivske	Ukraine	B	Not operating		yes				2000000[m]
Mezhyrichne	Ukraine	B	Operating	Ti	yes				2000000[m]
Byrzulivske	Ukraine	B	Operating	Ti	yes				2000000[m]
Orkheia	Norway	B	Historic		no	900000 (t of rutile)			900000 (t of rutile)
Selvåg	Norway	C	Not exploited		no	1834800 (t of ilmenite)			1834800 (t of ilmenite)
Saurdal	Norway	C	Abandoned		no	1500000 (t of ilmenite)			1500000 (t of ilmenite)
Mustavaara	Finland	C	Closed		no	1372639			1372639
Peräneva	Finland	C	Not exploited		no	1284437			1284437
Kauhajärvi	Finland	C	Not exploited		no	1056908			1056908
Rødsand	Norway	C	Abandoned		no	413600 (t of ilmenite)		563288	976888 (t of ilmenite)
Thule	Greenland	C	Not exploited		no	887376			887376
Pyhäjärvi	Finland	C	Not exploited		no	662069			662069
Kairineva	Finland	C	Not exploited		no	650744			650744

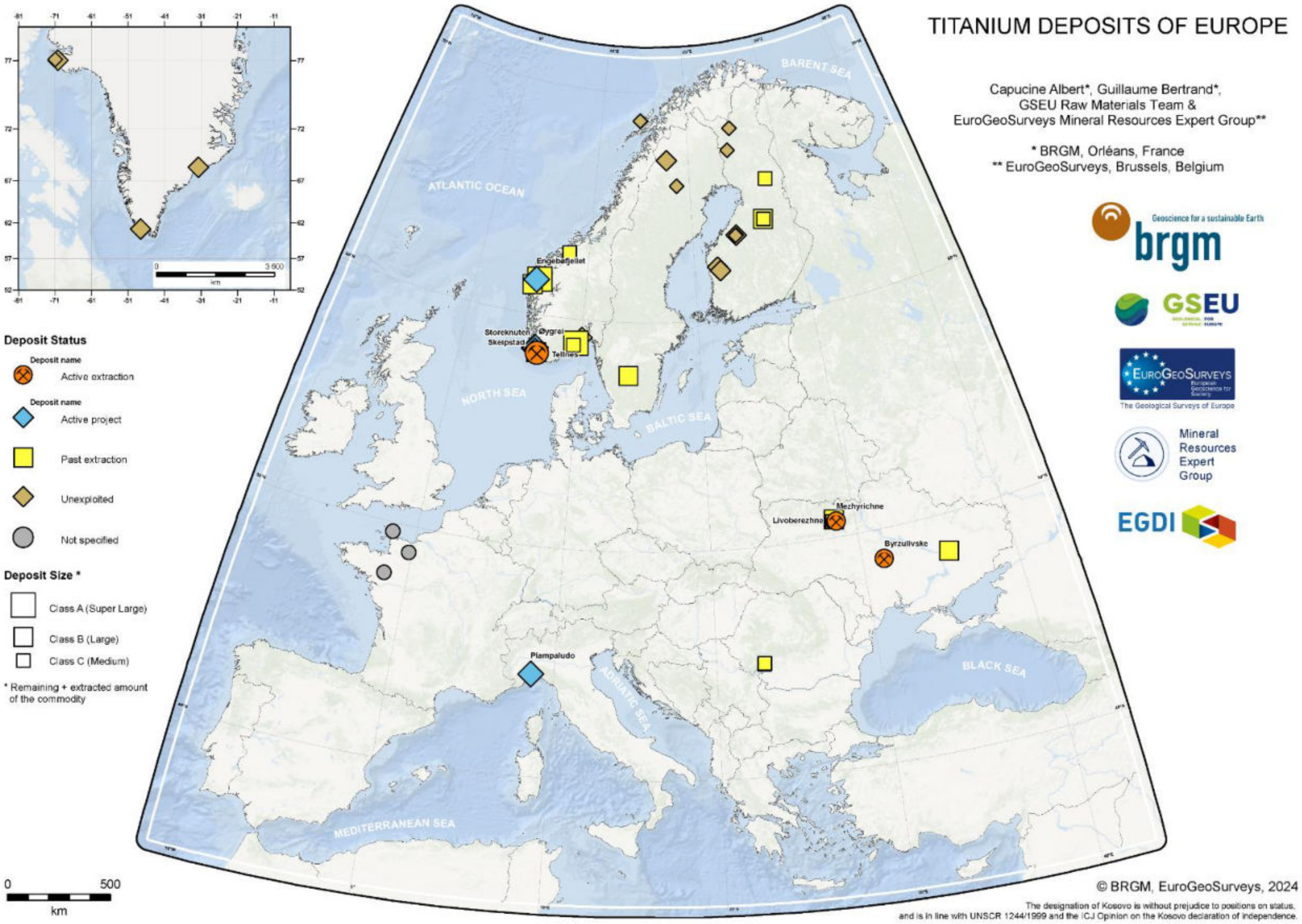
Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endow-ment (t)
Teillay	France	C			no	640000			640000
Karhujupukka	Finland	C	Not exploited		no	537795			537795
Vuorokas	Finland	C	Closed		no	357482		101100	458582
Lylyneva	Finland	C	Not exploited		no	386648			386648
Pentinpuro	Finland	C	Not exploited		no	350301			350301
Jerfojaure	Sweden	C	Not exploited		no	300258			300258
La Glacerie	France	C			no	200000			200000
Saint Pierre-du-Bû	France	C			no	200000			200000
Ohaba-Pestisani	Romania	C	Closed		yes				200000[m]
Ohaba-Caimacani	Romania	C	Closed		yes				200000[m]
Verkhnyo-Irshynske	Ukraine	C	Not operating		yes				200000[m]
Livoberezhne	Ukraine	C	Operating	Ti	yes				200000[m]
Lindvikkollen	Norway	C	Historic		no	94500 (t of rutile)			94500 (t of rutile)

[m] minimum estimate
* reserves not included in resources

Table 58: *Titanium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – titanium contained (tons of X)	Category
Finland	**1372639** (TiO_2) **5172935** (TiO_2) **27828903** (TiO_2)	2 – mineral resources 3 – compliant historical 4 – historical or non-compliant
France	**1040000** (TiO_2)	4 – historical or non-compliant
Greenland	**11951776** (TiO_2) **8111860** (TiO_2)	2 – mineral resources 4 – historical or non-compliant
Italy	**9000000** (rutile)	1 – mineral reserves
Norway	**13583700** (rutile) + **229423800** (ilmenite) **6994500** (rutile) + **117148400** (ilmenite)	2 – mineral resources 4 – historical or non-compliant
Sweden	**13311438** (TiO_2) **7806708** (TiO_2)	2 – mineral resources 4 – historical or non-compliant

Figure 31: *Map of titanium deposits in Europe.*



3.31. Tungsten (W)

In most deposits, tungsten is mined as the primary commodity, sometimes in association with tin and other minor associated commodities such as bismuth, arsenic and boron. In Europe, significant tungsten deposits can be found in Portugal and Spain.

Table 59: *Main European tungsten deposits identified in 2024. Tonnages are in tons of WO_3.*

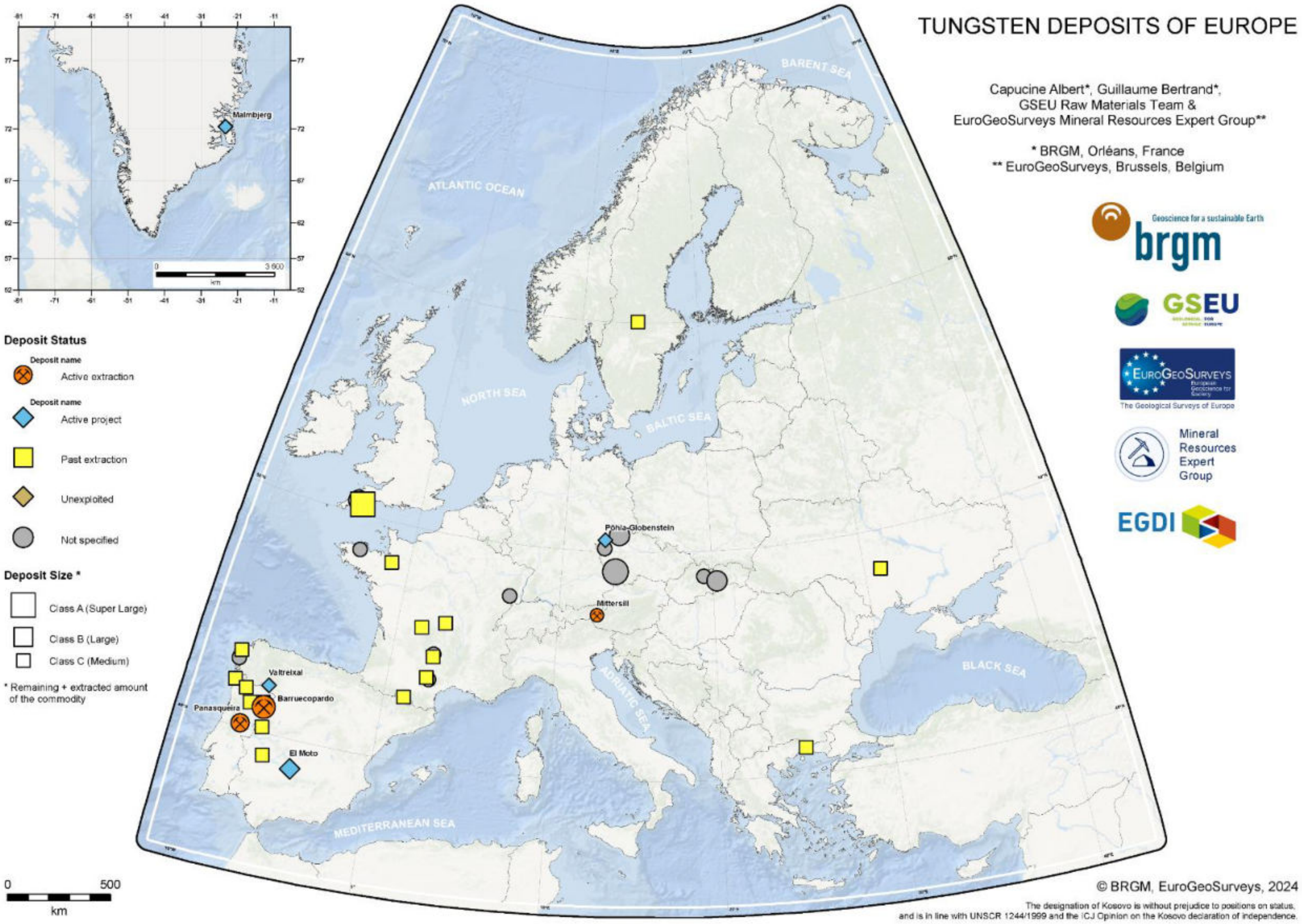
Name	Country	Class	Deposit status	Commodities currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Drakelands	UK	A	Not operating		no	265298	147960*		413258
Barruecopardo	Spain	A	Operating	W	no	18876		260000	278876
Kašperské Hory	Czechia	A			yes				200000[m]
Panasqueira	Portugal	B	Operating	W	no	52781	6418	107000	159781
El Moto	Spain	B	Feasibility		no	74204			74204
Redmoor	UK	B			no	65520			65520
Cínovec	Czechia	B			yes				50000[m]
Ochtiná	Slovakia	B			yes				50000[m]
La Parrilla	Spain	C	Not operating		no	48917			48917
Pöhla-Globenstein	Germany	C	Feasibility		no	41606			41606
Valtreixal	Spain	C	Feasibility		no	35828	8667		35828
Lagoaça	Portugal	C	Abandoned		no	35113		440	35553
Malmbjerg	Greenland	C	Under devel-opment		no	30264			30264
Fumade	France	C			no	26970			26970
Mina "La Lapa"	Spain	C	Closed		no	22000			22000
Borralha	Portugal	C	Abandoned		no	2100		18170	20270
Salau	France	C	Historic		no	3516		13756	17272
Yxsjöberg	Sweden	C	Closed		no			16840	16840
Santa Comba	Spain	C	Closed		no	16038	11220		16038
Montbelleux	France	C	Historic		no	11200		247	11447
Montredon-Labes-sonnié	France	C	Historic		no	10500		864	11364
Dobra	Ukraine	C	Not operating		no	11175			11175
Coat-An-Noz	France	C			no	11000			11000
San Finx	Spain	C			no	9600			9600
S. Pedro das Águias (Tabuaço)	Portugal	C	Abandoned		no	9000			9000
La Bosse	France	C	Historic		no	5000		3861	8861
Auxelles-Haut	France	C			no	8500			8500
Covas	Portugal	C	Abandoned		no	7706		567	8273
Kimmeria	Greece	C	Historic		no	7600			7600
Leucamp	France	C			no	7000			7000
Enguialès	France	C	Historic		no	5284		1300	6584
Puy les Vignes	France	C	Historic		no	1158		3970	5128
Mittersill	Austria	C	Operating	W	yes				5000[m]
Krasno	Czechia	C			yes				5000[m]
Jasenie	Slovakia	C			yes				5000[m]

[m] minimum estimate
* reserves not included in resources

Table 60: *Tungsten resources/reserves from the main deposits in Europe.*

Country	Remaining resources – tungsten contained (tons of WO_3)	Category
France	**90128**	4 – historical or non-compliant
Germany	**41606**	4 – historical or non-compliant
Greece	**7600**	4 – historical or non-compliant
Greenland	**30264**	4 – historical or non-compliant
Portugal	**6418** **46363** **53919**	1 – mineral reserves 2 – mineral resources 4 – historical or non-compliant
Spain	**19887** **31987** **22000**	1 – mineral reserves 2 – mineral resources 4 – historical or non-compliant
UK	**147960** **265300**	1 – mineral reserves 2 – mineral resources
Ukraine	**11175**	3 – compliant historical

Figure 32: Map of tungsten deposits in Europe.



3.32. Vanadium (V)

Vanadium is a rare metal, and it often occurs in association with iron and titanium ores, as it tends to substitute for iron or aluminium in certain minerals. Vanadium is typically extracted as a by-product of uranium mining, titanium mining, and iron ore processing.

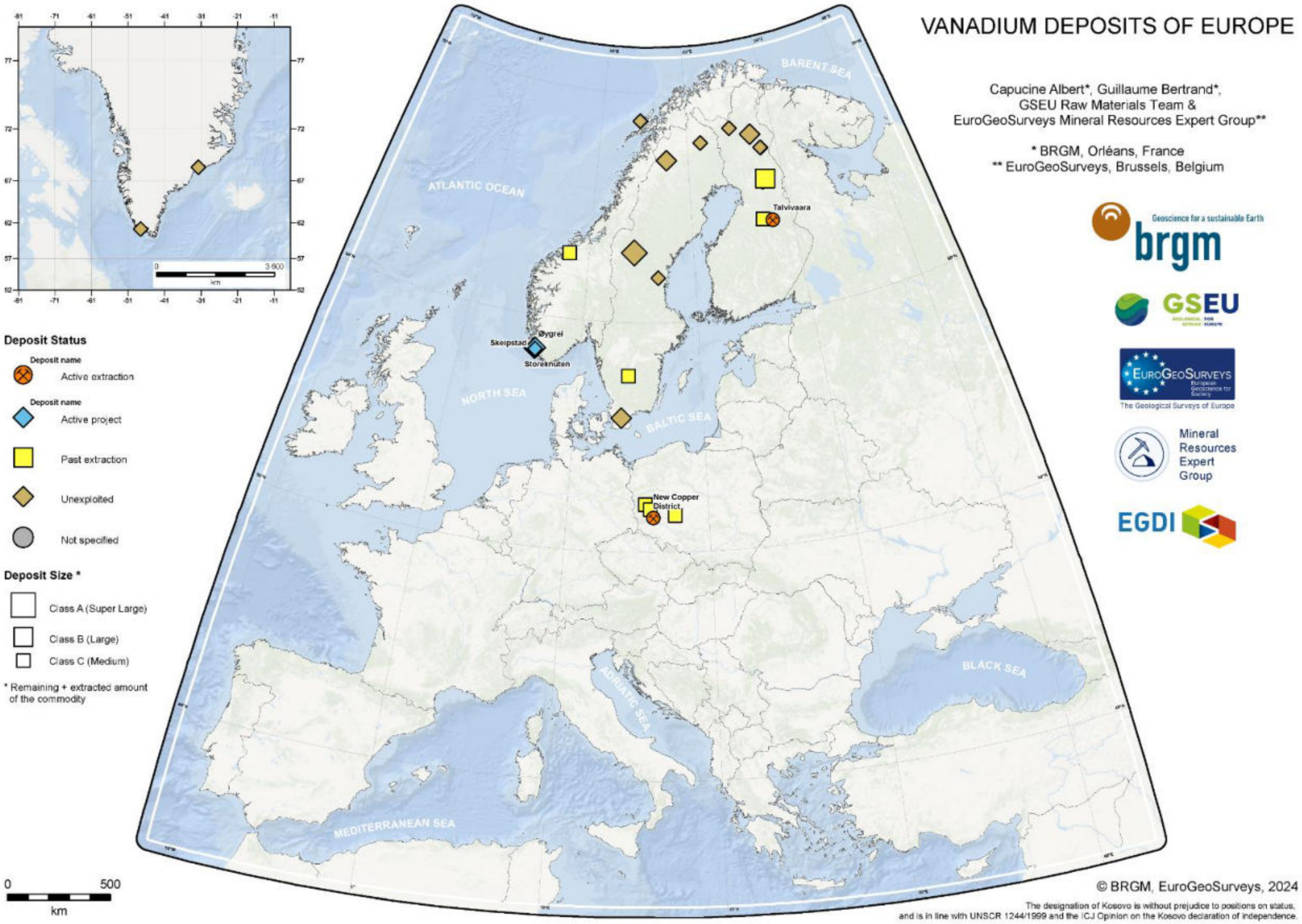
Table 61: *Main European vanadium deposits identified in 2024. Tonnages are in tons of V metal.*

Name	Country	Class	Deposit status	Commodi-ties currently mined	Confiden-tial	Resources (t)	Reserves (t)	Extracted (t)	Total endowment (t)
Häggån	Sweden	A	Not exploited		no	3408500			3408500
Storeknuten	Norway	B	Feasibility		no	1583500			1583500
Øygrei	Norway	B	Feasibility		no	628000			628000
Koitelainen UC	Finland	B	Not exploited		no	280000			280000
Routivare	Sweden	B	Not exploited		no	280000			280000
Hörby	Sweden	B	Not exploited		no	254624			254624
Mustavaara	Finland	B	Closed		no	201780		27485	229265
Talvivaara	Finland	C	Operating	Ni, Co	no	189222			189222
Smålands Taberg	Sweden	C	Closed		no	180000		1836	181836
Skeipstad	Norway	C	Feasibility		no	153600			153600
New Copper District	Poland	C	Operating	Cu, Ag, Pb, Ni, Re, Au	no	146110		2730	148840
Skaergaard	Greenland	C	Not exploited		no	122341			122341
Otanmäki	Finland	C	Closed		no	36400		64468	100868
Airijoki	Sweden	C	Not exploited		no	99232			99232
Rødsand	Norway	C	Abandoned		no	65000		30000	95000
Koitelainen V	Finland	C	Not exploited		no	73294			73294
Akanvaara UC	Finland	C	Not exploited		no	72400			72400
Akanvaara Gabbro	Finland	C	Not exploited		no	68000			68000
Selvåg	Norway	C	Not exploited		no	66000			66000
Isortoq	Greenland	C	Not exploited		no	56240			56240
Sumåssjön	Sweden	C	Not exploited		no	46830			46830
Pyhäjärvi	Finland	C	Not exploited		no	46305			46305
Sulmierzyce Północ	Poland	C	Not operating		no	44540			44540
Mozów	Poland	C	Not operating		no	31310			31310
Soidinvaara	Finland	C	Not exploited		no	25500			25500
Nowa Sól	Poland	C	Not operating		no	22210			22210

Table 62: *Vanadium resources/reserves from the main deposits in Europe.*

Country	Remaining resources – vanadium contained (tons of V metal)	Category
Finland	**275074** **717827**	2 – mineral resources 4 – historical or non-compliant
Greenland	**56240** **122341**	2 – mineral resources 4 – historical or non-compliant
Norway	**2365100** **131000**	2 – mineral resources 4 – historical or non-compliant
Poland	**244170**	2 – mineral resources
Sweden	**4042356** **226830**	2 – mineral resources 4 – historical or non-compliant

***Figure 33:** Map of vanadium deposits in Europe.*



4. Pan-European CRM Prospectivity Mapping

4.1. Methodology

4.1.1. Mineral Prospectivity Mapping (MPM)

An objective of work package 2 of the GSEU project is to produce predictive assessments – in the form of prospectivity maps - of CRM based on GIS exploration tools at continental scale, in order to identify high potential mineral provinces. In the past, economic geologists used a light table to simply overlay different thematic maps to examine spatial relationships and analogue data integration between important multi-disciplinary criteria to guide exploration and produce mineral potential and other relevant maps. Nowadays, it is possible to collect and store the data and information in digital formats and to use different GIS and statistical approaches to deliver maps showing favourable areas referring to a specific commodity. Carranza (2017) describes mineral prospectivity mapping (MPM- also termed mineral prospectivity modelling) as “quantifying and mapping of the likelihood that mineral deposits may be found by exploration in a study area”. The basic purpose of prospectivity mapping is to assess the spatial distribution of the favourability of occurrence of a non-random phenomenon (assuming that a phenomenon cannot be predicted if it is purely random). In the case of mineral prospectivity mapping, the phenomenon is the occurrence of a mineralization. A large number of mineral prospectivity mapping methods exist. They can be grouped in two categories:

- **The “expert guided” methods** rely on the existing knowledge of experts, in the form of e.g., exploration guides or metallotects. These guides are searched to discover analogues and hopefully new mineralization. This is more or less how mineral exploration was empirically conducted by economic geologists in the past centuries. The development of computers and databases during the last decades allowed to automatically process larger volumes of data and thus improve the accuracy and reliability of the methods;
- **The “data driven” methods** rely more on the processing of data to deduce “knowledge” (“learning” from input datasets) that is then used to identify the areas that are favourable to discover new mineralization. Data driven methods largely progressed in the past decades with the tremendous development of computing capacities and databases.

When it comes to mineral prospectivity mapping at continental scale (which is the goal of this work), encompassing huge geographic coverage, numerous geological environments and large volumes of data, data driven methods are appropriate. In this work, we have used a data driven approach, the DBA (Disc Based Association; Vella, 2022). It is a new supervised Machine Learning method that improves the CBA (Cell Based Association) developed by BRGM (Tourlière et al., 2015), and that was used for producing the mineral prospectivity maps of the GeoERA FRAME project (Bertrand et al., 2021).

4.1.2. Common Issues in Mineral Prospectivity Mapping

Most data driven mineral prospectivity mapping methods are based on unequivocal relationships between points (e.g., known deposits) and the cartographic entities that contain them (pixels or polygons associated with, for instance, geological information). The knowledge “learned” by the process will be solely based on this unequivocal relationship. For instance, a deposit will unequivocally be linked to the lithology polygons that contains it, without considering surrounding lithologies. This “shortcut” may lead to several issues that could significantly bias the results.

The first issue resides in the uncertainties in polygon contours and point location. Cartographic objects are drawn with a certain error in their location that could be significant, especially at continental scale. That may result in a wrong association between a point (deposit) and a polygon (lithology). In addition, geological maps display surficial formation that could cover large areas but are not related to mineralization (Quaternary covers, for instance).
The second issue resides in the fact that the area of polygons are often considered a relevant parameter for weighting. That is the case for instance in the Weight of Evidence method (Bonham-Carter et al., 1988, 1989; Agterberg et al., 1990) where areas of lithological formations are used to calculate density of deposits. This may lead to artefacts because geology is in 3D and the area extension of a formation is not necessarily related to its overall importance.
The third issue resides in the spatial distribution of points that is often not considered in data driven mineral prospectivity methods. Heterogeneous distribution of data points may lead to the inappropriate generalization of a local feature to a whole formation. For instance, skarn deposits are not located in a whole carbonate formation, but along its contact with intruding magmatic bodies.
To solve these issues, considering the geological environment around known deposits and "learn" from this information to assess the favourability is more appropriate than considering solely the "point-polygon" unequivocal link. Both the CBA and DBA methods have been developed with this underlying base principle. As we explain below, the DBA is an improvement of the CBA. The DBA is the method we have used to produce the GSEU mineral prospectivity maps.

4.1.3. Overview of the Cell Based Association Method

The application of the CBA method relies on a succession of relatively simple steps of data processing and calculation. The basic needs in terms of data to apply the method are 1) a set of known deposits containing the targeted commodity in the area of study (learning set) and 2) a map of relevant geological features.
The **first step** of the CBA method is to superimpose a regular grid ("cells") over the area of study. The size of the cells is an important parameter that is directly connected to the scale of the input map. If they are too small, most of them will intersect only one lithology polygon, if they are too large, they will intersect "too many" (if not all) lithology polygons.
In the **second step**, an attribute table is built from the intersection between the grid and the map polygons. This attribute table codes the presence (1) or absence (0) of each lithology in each cell of the grid. It then provides a "lithological spectrum" that describes the lithological associations in all cells of the grid (Figure 34). Note that the area of the intersection between lithological polygons and cells is not considered, owing to the fact that it is likely meaningless in 2D (as geology is 3D).
In a **third step**, we identify the lithological associations related to known deposits. To do so, a buffer of an area equal to those of the cells is drawn around each deposit. Lithological associations in all buffers are coded similarly to grid cells. At the end of this process, we have built two attribute tables to describe lithological associations: one for all cells of the grid and one for the buffers around known deposits. The lithological associations in buffers are associated with deposits and are then considered favourable.
The **last step** is to compare lithological associations of the grid cells and buffers, and score associations in cells based on their similarity to those in buffers that are considered favourable. In the GeoERA FRAME projects, several algorithms for score calculation were tested, based on frequency ratios (Bertrand et al., 2021).
Despite its advances compared to usual MPM methods, the CBA method still suffered some limitations. Among them, one is that the aggregation of input data in grid cells decreases the resolution of the resulting favourability map. Another one is that the square shape of the cells induces an anisotropic bias. Depending on the orientation and location of the grid, a same object could be included in different

environments (Figure 35). The over- or under-representation of these objects may affect the ranking and favourability scores.

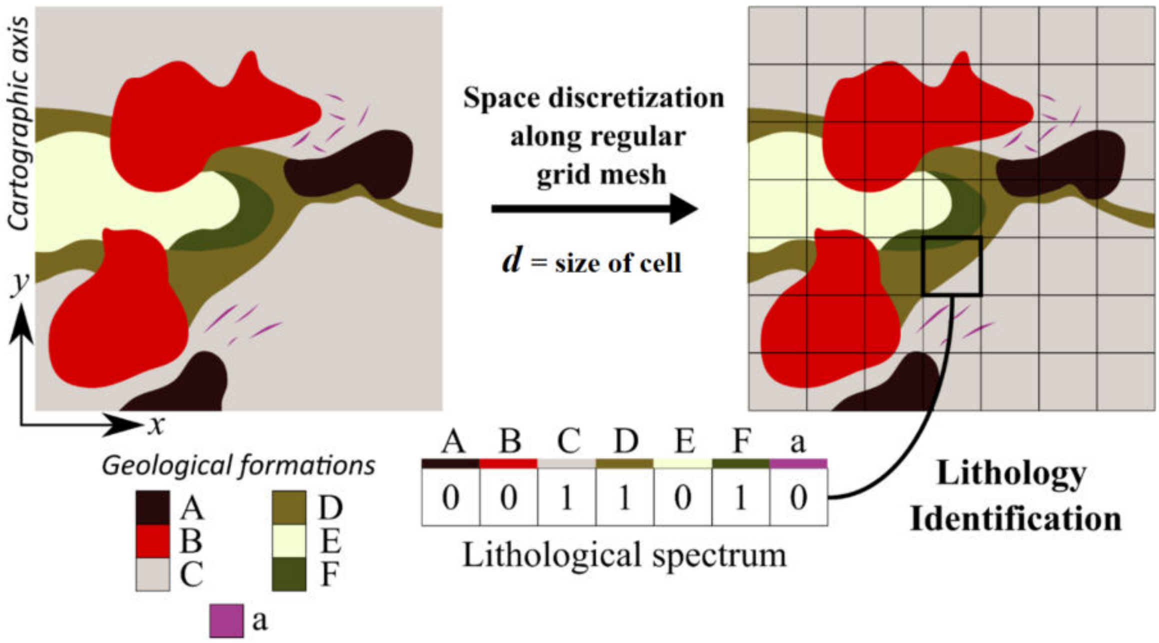


Figure 34: *Basic principle of the CBA (Cell Based Association) method, as described by Tourlière et al. (2015).*

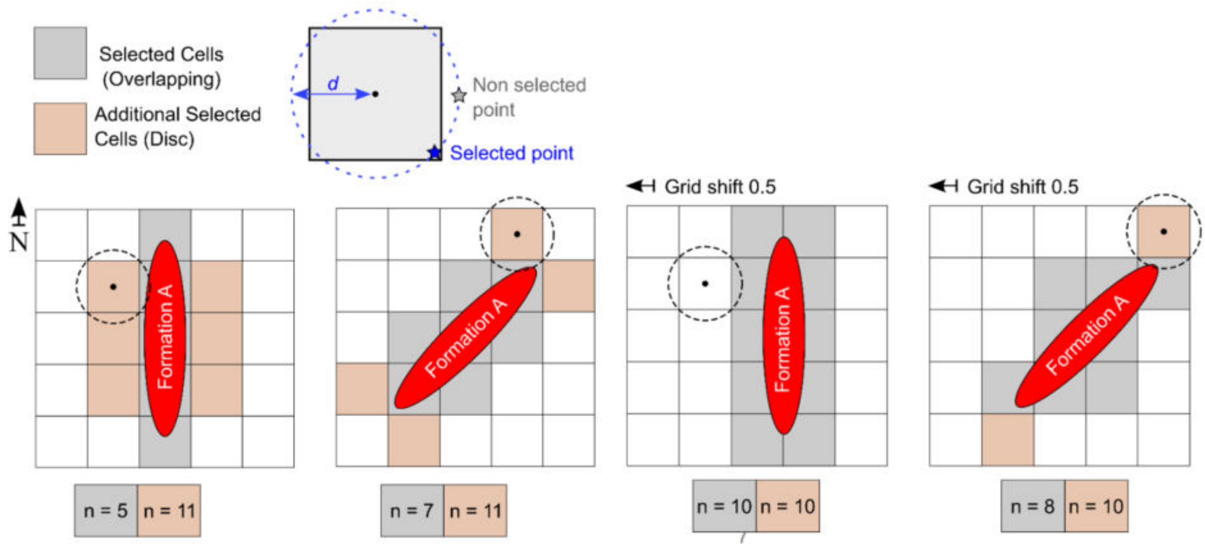


Figure 35: *Impact of the relative orientation and position of the CBA square cells grid on the integration of a same geological object (Vella, 2022). The orange cells are selected using the DBA method, as detailed below.*

4.1.4. Overview of the Disc based Association Method

To solve issues inherent to the CBA, the DBA method has been developed (Vella, 2022). Basically, the DBA replaces the CBA data aggregation in a regular square cells grid by search discs along a regular mesh (Figure 36). The lithological spectrum is then the association of lithologies contained in the search disc (DBA) instead of the square cell (CBA). That allows decoupling the resolution of the data aggregation (radius R of the search discs) and the resolution of the final favourability map (interdistance d between neighbouring points in the regular mesh). In addition, the shape of the search disc solves the anisotropic bias of the CBA square-shaped cells. Another benefit is that the search radius R of the discs can be adapted to input data. That allows for instance to select different search radius for different geological objects (e.g. faults and lithological units).

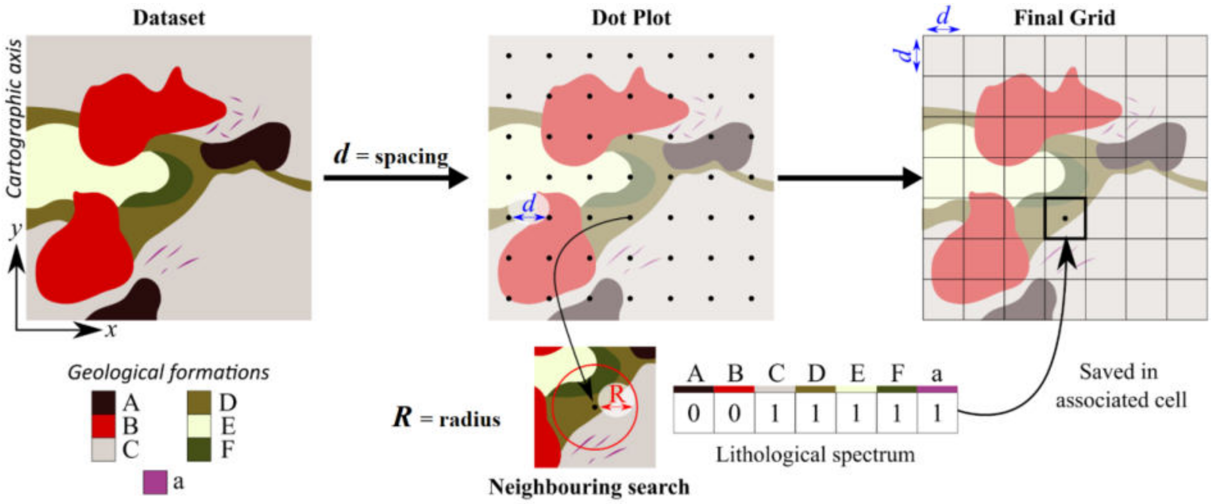


Figure 36: *Basic principle of the DBA (Disc Based Association) method of aggregating input data in search discs cantered on a regular grid mesh (Vella, 2022).*

In addition to the aggregation of data via search discs over a regular mesh, the DBA method includes Random Forest (RF) algorithms to calculate the favourability scores. RF is a supervised machine learning technique that creates multiple decision trees and combines their outputs for more accurate predictions. For both regression and classification tasks, it works by building a "forest" of n decision trees using random subsets of the data and features (stratified bootstrap random sampling for each tree of the forest). The remaining part of data and features is used to evaluate the model. Each tree makes its own prediction, and the final result is determined by averaging (for regression) or majority voting (for classification; Figure 37). This ensemble approach helps to reduce overfitting and makes the model more robust than single decision trees. RF handles both continuous (e.g. airborne geophysics) and discrete (e.g. lithology polygons, geochemical analyses, etc.) data. It also provides insights into feature importance. These last points allows the identification of the most pertinent features that are favourably associated with potential mineralization.

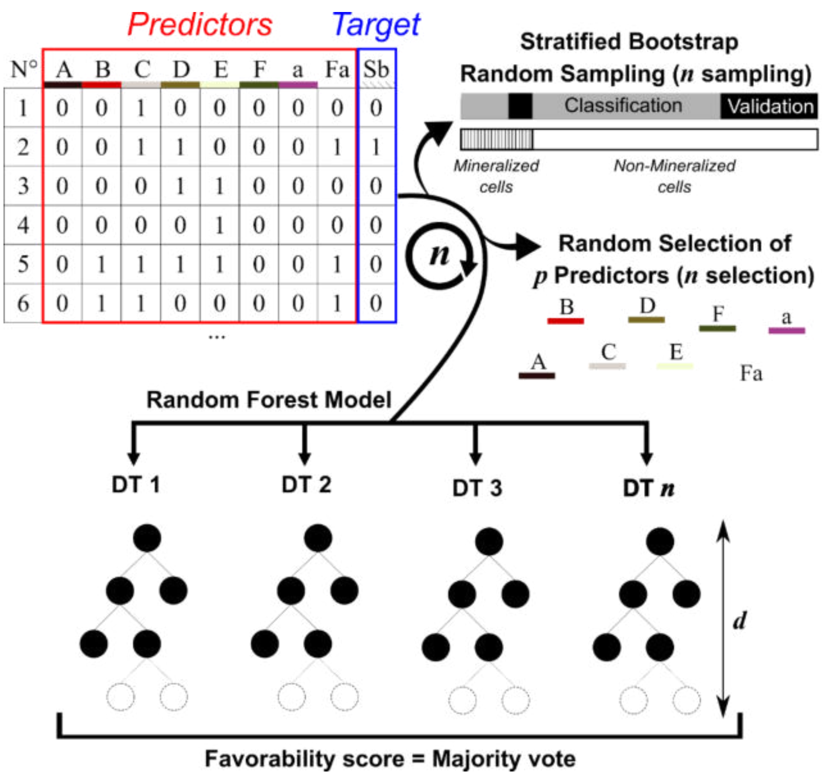


Figure 37: *Basic principle of the RF method; Predictors are geological features (lithologies, faults, etc) and target are known deposits (Vella, 2022).*

To optimize the results of RF regression, it is important to properly define hyperparameters. Optimizing the hyperparameters consists of defining the input parameters (such as the number of decision trees, the depth of the trees, the number of predictors, etc.) that will optimize the model for a given input dataset. The performance of the model is evaluated via different types of metrics, such as the ROC (Receiver Operating Characteristic) curve, the AUC (Area Under Curve) score, the confusion matrix, etc.

4.1.5. Performance Assessment

To evaluate our prospectivity models, we use evaluation metrics that assess their performance. The metrics we have used in the present study are:

- Confusion Matrix, accuracy, precision and recall scores
- ROC curve and AUC score

Confusion Matrix: this matrix visualizes the binary classification results, indicating the True/False Negatives/Positives with color, percentages and counts for each category.

- **TP** = True Positive / **TN** = True Negative
- **FP** = False Positive / **FN** = False Negative

From the Confusion Matrix, we calculate 3 scores that are:

- **Accuracy** = $\frac{\text{TP+TN}}{\text{all}}$

  The accuracy score measures the ratio of cells that were correctly predicted by the model. The closer to 1, the more precise the model

- **Precision** = $\frac{\text{TP}}{(\text{TP+FP})}$

  The precision score measures the ratio of positive predictions that were initially positive cells. A precision equal or close to 1 indicates a predictive model that is too discriminating and likely overfit

- **Recall** = $\frac{\text{TP}}{(\text{TP+FN})}$

  The recall score measures the ratio of mineralized cells that were correctly classified by the predictive model. The closer to 1 the better mineralized cells were classified.

ROC (Receiver Operating Characteristic) curve: it is a binary classification multi-threshold metric, where ideal performance corner is on the top-left of the plot. This visualization helps users understand the trade-offs between true positive rate (**TPR**) and false positive rate (**FPR**), aiding in model selection and evaluation.

- **True Positive Rate** (**TPR**) = $\frac{\text{TP}}{\text{TP + FN}}$
- **False Positive Rate** (**FPR**) = $\frac{\text{FP}}{\text{FP +TN}}$

The AUC (Area Under Curve) score of the ROC curve summarizes the model performance across different classification thresholds. It is comprised between 0 and 1, the closer to 1 the more performant the model.

4.2. Building the Prospectivity Models

4.2.1. Input Data

MPM requires homogeneous and harmonised input datasets fully covering the area of study. The geological dataset that has been used for this work is the 1:1,500,000 Geological Synthesis of Europe (Billa et al., 2008) in vector shapefile format. This dataset contains polygons of lithostratigraphic units (Figure 38) and polylines of tectonic structures (faults; Figure 39) covering the whole continental geographic Europe. It is one of the 'deliverables' of the BRGM R&D project 'GIS Europe' that was initially undertaken as part of the ESF (European Science Foundation) GEODE (Geodynamics and Ore Deposit Evolution) programme, ABCD (Alpine-Balkan-Carpathian-Dinarides) sub program. The first synthesis produced within this programme (Metallogenic Map of Central and Southeastern Europe) was later completed with scientific input from several projects, e.g. SIG Mines France (BRGM), GIS Karelia (RFML – Russian-French Metallogenic Laboratory), GIS Caucasus (BRGM – CNRS). The coverage has mainly been created by digitization and synthesis of published national geological maps after applying a standardized legend based on the age and the lithology of the mapped units. The input maps from all countries have been published at a 1:500,000 scales or less and permits verification of the synthesis at a 1:1,500,000 scale. Some key areas, such as the Alps, have been completely redrawn. The Fenno-Scandinavian part of the map has been produced by the Geological Surveys of Finland, Norway, Russia and Sweden. Note that for the present study, polygons of Pliocene and Quaternary ages have been removed.

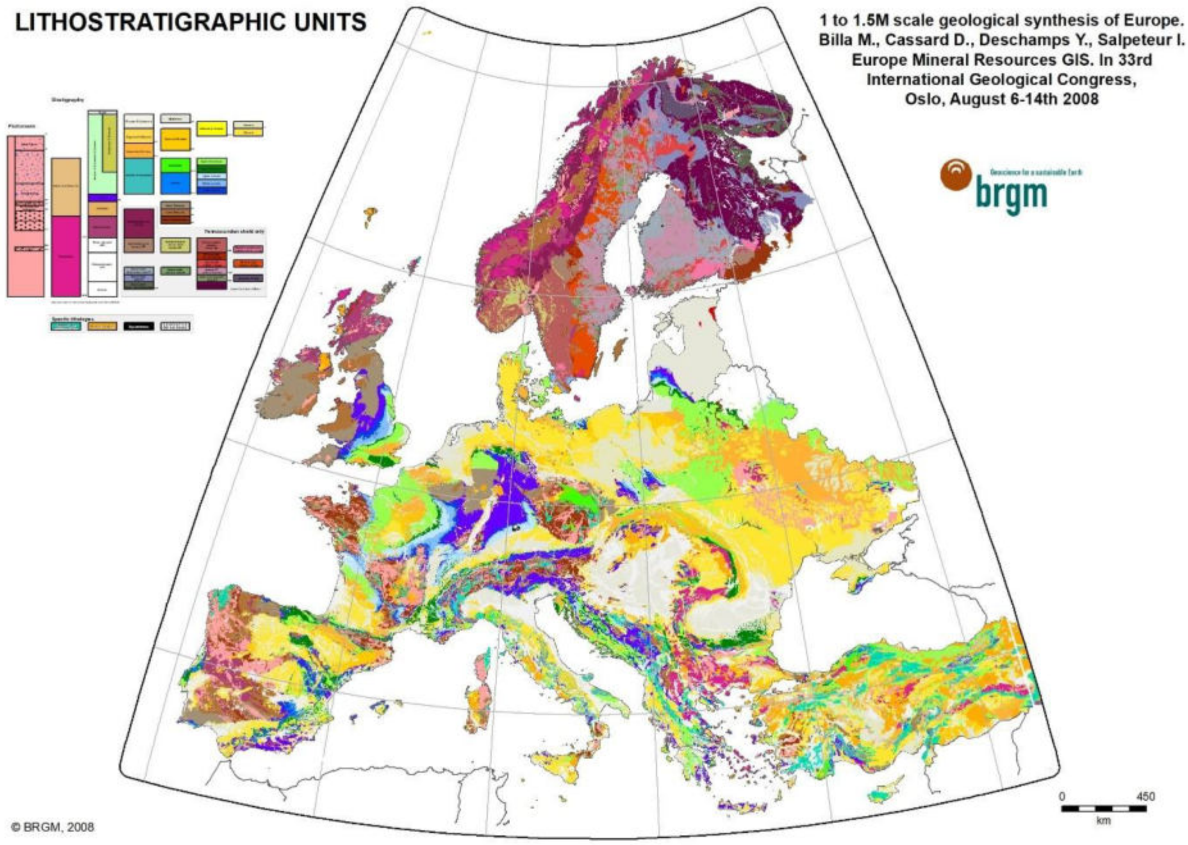


Figure 38: *Lithostratigraphic units of the 1 to 1.5 million scale Geological Synthesis of Europe (Billa et al., 2008) that was used in the present study.*

In the present report, we have produced pan-European mineral prospectivity maps for 11 critical raw materials that are cobalt, copper, lithium, nickel, niobium, magnesium, manganese, antimony, tantalum, vanadium and tungsten. For mineral deposits, we have used the GSEU dataset of medium, large and super large deposits (classes A to C) presented herein. This dataset was completed with small and very small deposits (classes D and E) extracted from the MIN4EU and, when appropriate, the ProMine mineral deposits databases. Small and very small deposits were included when the total population remained within a «reasonable» number (ideally between 50 and 500). For instance, the total number of A to E Cu deposits was over 3500. This population was too high and would have blurred the prospectivity model. In that case, only A to C deposits were considered, for a total of 137 deposits. On the other hand, all lithium deposits from class A to E were considered, for a total of 105 deposits. For some commodities, there was no class A deposit. This is the case for cobalt, which has only classes B to E, for a total of 261 deposits.

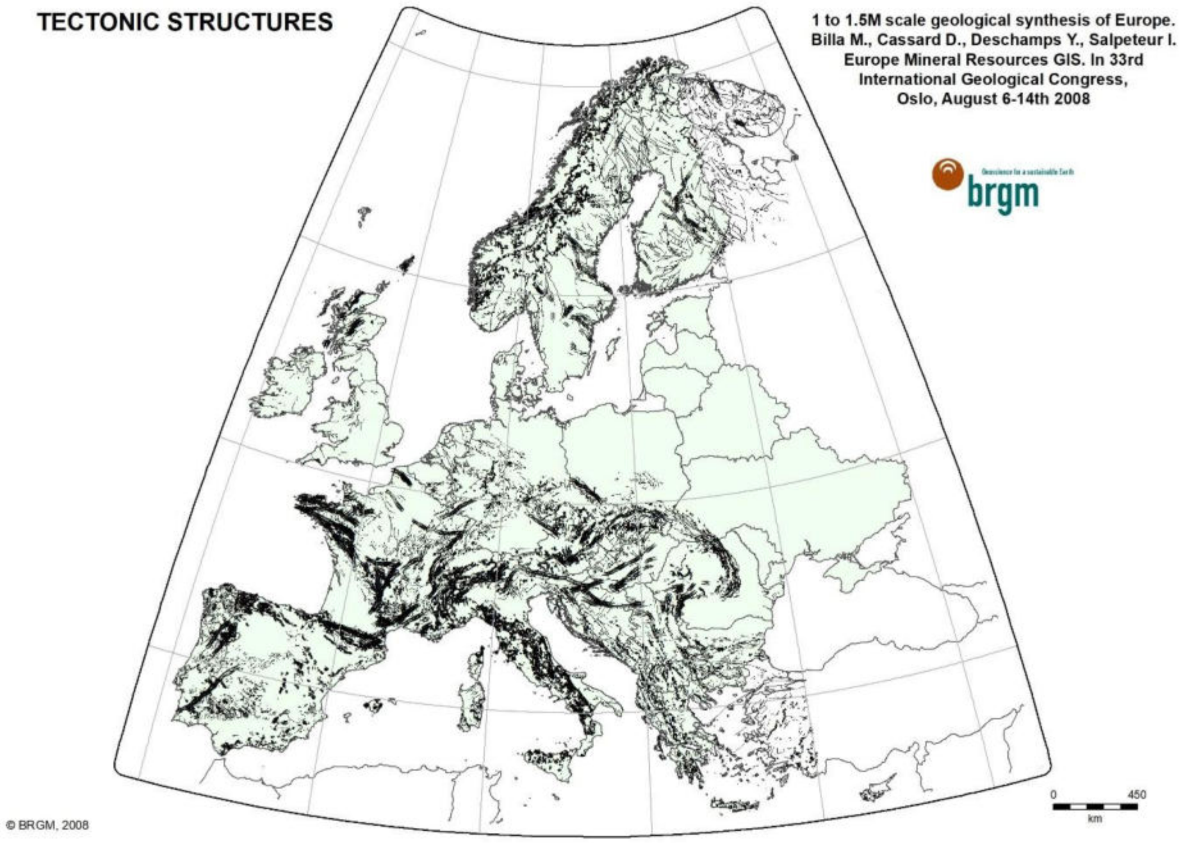


Figure 39: *Tectonic structures of the 1 to 1.5 million scale Geological Synthesis of Europe (Billa et al., 2008) that was used in the present study.*

4.2.2. Modelling Parameters

To produce the prospectivity maps with the DBA and RF approach, we have used the following parameters:

- Search discs radius (R) of 7.5 km;
- Interdistance between neighboring search discs (d) of 5 km. This gives a total of 211162 cells on the scale of continental Europe;
- R/d ratio of 1.5;
- Processing buffer of 5 km to associate deposits and faults;
- Deposits were weighted on their class, with a Log3 scale weighting for datasets with 5 classes (weights of 1, 3, 9, 27 and 81 from very small to super large deposits), a Log4 scale for datasets with 4 classes (weights of 1, 4, 16 and 64 from smaller to larger deposits) and a Log5 scale for datasets with 3 classes (weights of 1, 5 and 25 from smaller to larger deposits);
- RF hyperparameters were defined with random cross-validation, 100 iteration, 3 splits (i.e. 300 simulations), $\sqrt{n}$ predictors for each tree (n is the total number of predictors), trees depth between 5 and 15 (included) and number of trees between 100 and 500 (30 values randomly selected).

4.3. Prospectivity Maps

The following sections provide the mineral prospectivity maps produced by GSEU with the DBA & RF method and briefly describe the datasets that were used. In addition, ROC Curves and Confusion Matrixes, with associated scores, are provided in order to measure the performance of the predictive models. Note that each prospectivity map shows the spatial distribution a relative favourability for a given commodity. As such, it would be meaningless to compare prospectivity maps for different commodities one-to-one.

4.3.1. Cobalt (Co)

The prospectivity map for cobalt was produced with a set of 261 Co deposits, of class B to E (Table 63). According to the distribution of weights and deposits per class, the model is dominated by C (medium) class deposits. The resulting map is presented in Figure 41. The performance metrics of the prospectivity model (Figure 40) show a very good AUC score (0.91), a relatively low accuracy (0.304) due to the large distribution of scores toward higher values (69.63% false positives) and a perfect recall score of 1.

Table 63: *Distribution and weight, per class, of Co deposits that were used to model the favourability for cobalt mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	0	
B (large)	6	64
C (medium)	58	16
D (small)	98	4
E (very small)	99	1
Total:	261	

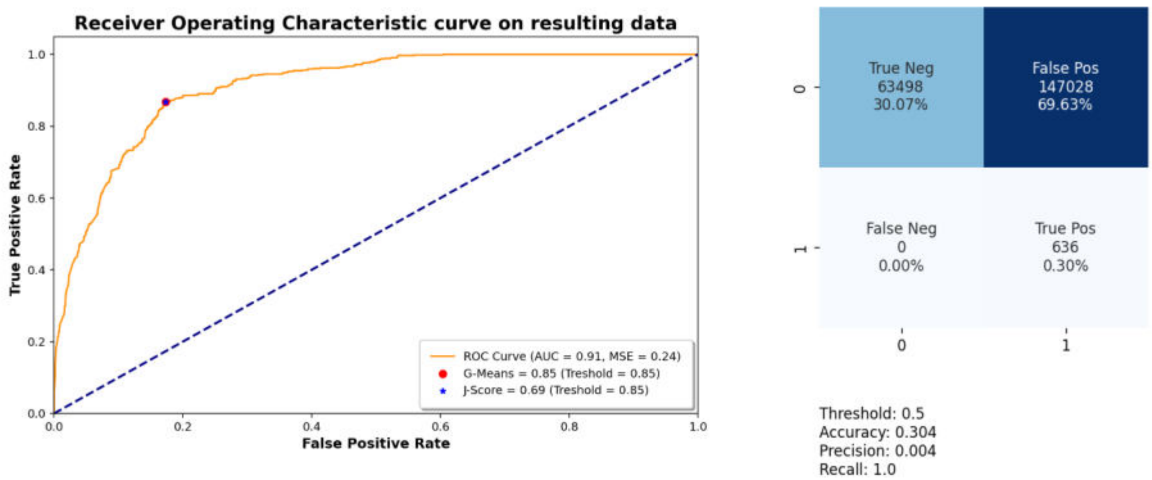


Figure 40: *Performance assessment of the favourability model for cobalt mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

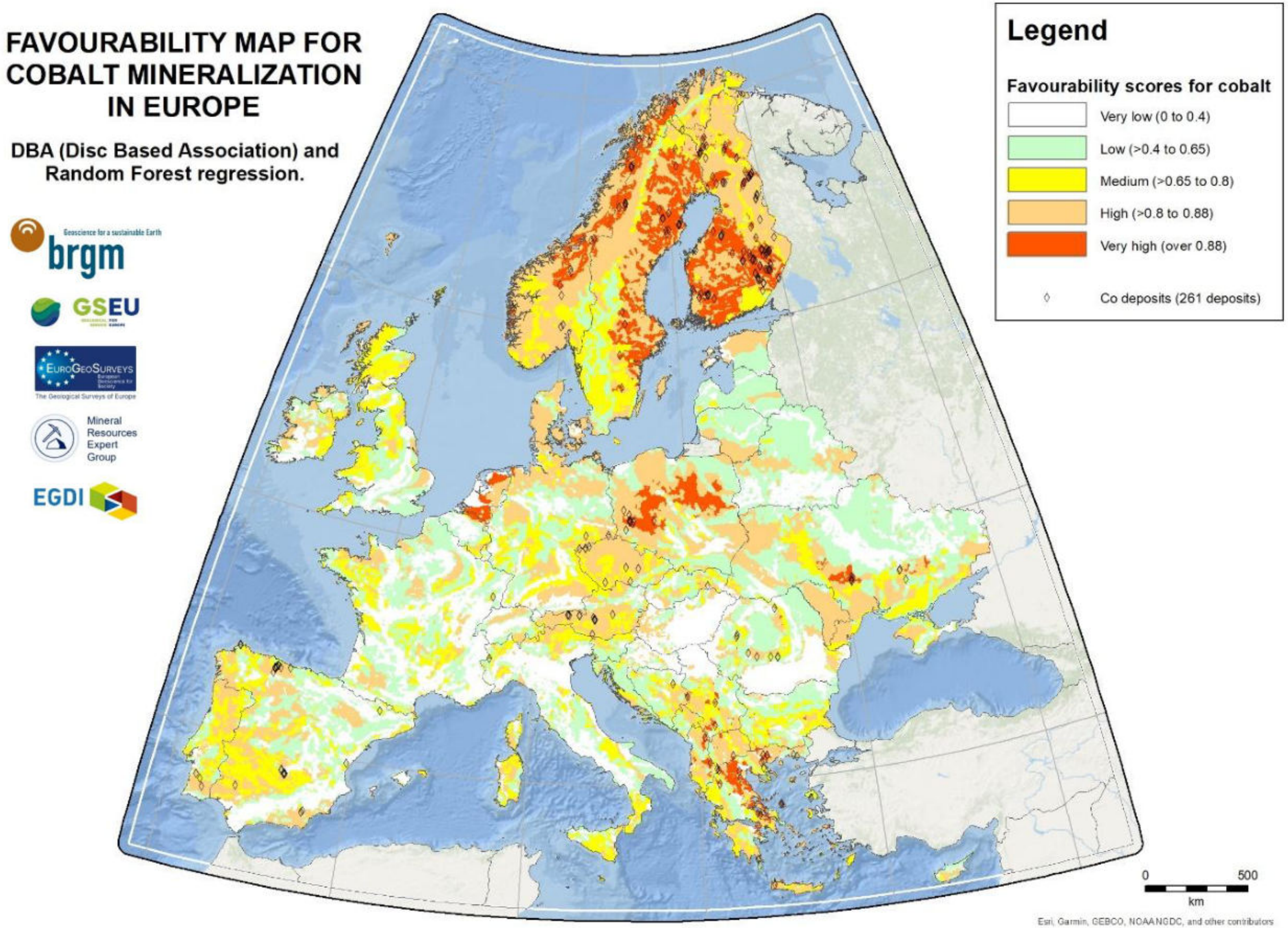


Figure 41: *Favourability map for cobalt mineralization in Europe, produced with the DBA & RF method.*

4.3.2. Copper (Cu)

The prospectivity map for copper was produced with a set of 137 Cu deposits, of class A to C (Table 64). 2092 class D and 1455 class E deposits were available in the MIN4EU and ProMine databases but were not used to avoid an oversized training dataset. Such large dataset would have been difficult to handle in terms of computing capacity, and would have likely diluted the favourability over the study area, resulting in poorer model performances. The resulting map is presented in Figure 43. The performance metrics of the prospectivity model (Figure 42) show an excellent AUC score (0.95), an average accuracy (0.575) and a perfect recall score of 1.

Table 64: *Distribution and weight, per class, of Cu deposits that were used to model the favourability for copper mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	2	25
B (large)	32	5
C (medium)	103	1
D (small)	0	
E (very small)	0	
Total:	137	

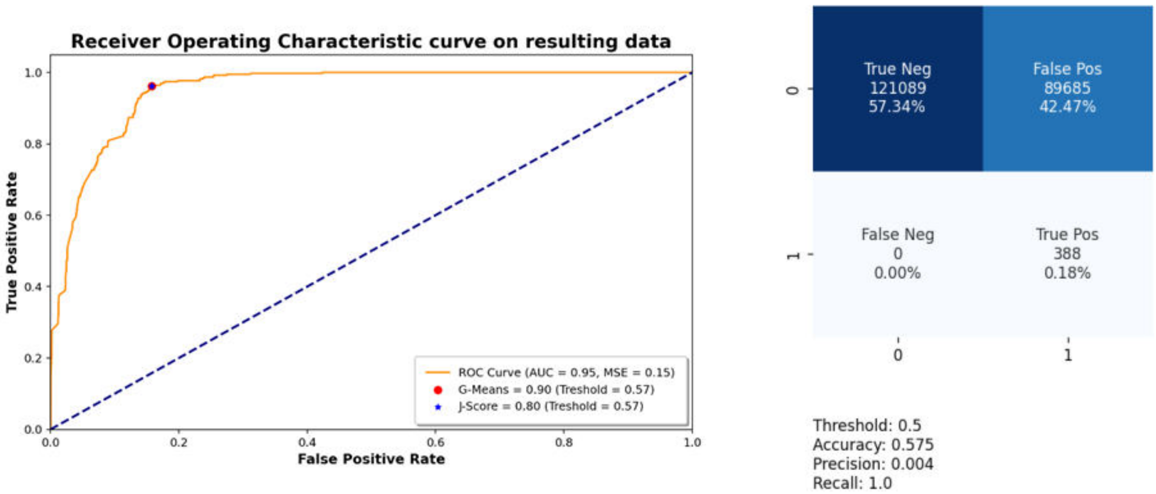


Figure 42: *Performance assessment of the favourability model for copper mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

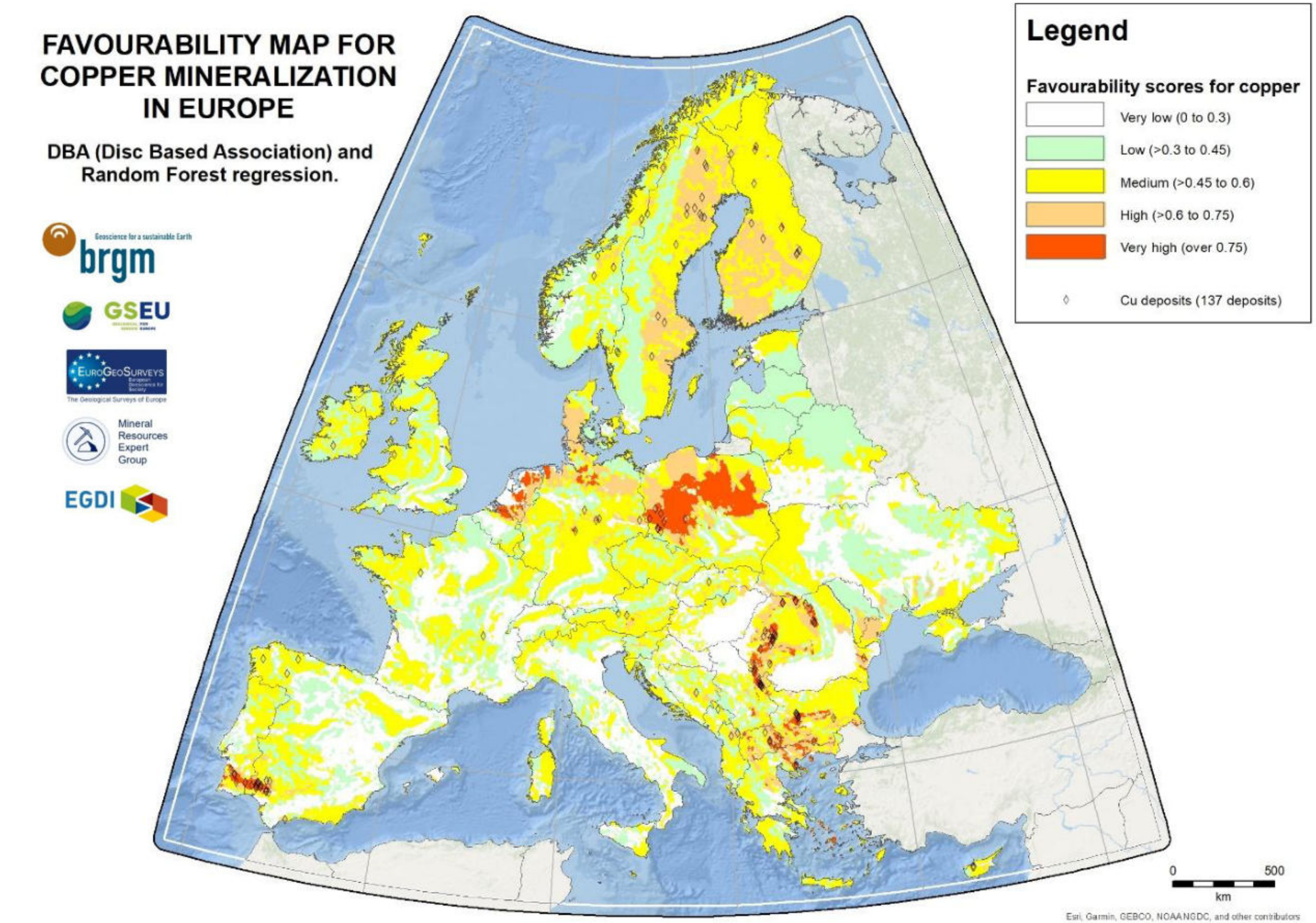


Figure 43: *Favourability map for copper mineralization in Europe, produced with the DBA & RF method.*

4.3.3. Lithium (Li)

The prospectivity map for lithium was produced with a set of 105 Li deposits, of class A to E (Table 65). According to the distribution of weights and deposits per class, the model is dominated by A (super-large) class deposits. The resulting map is presented in Figure 45. The performance metrics of the prospectivity model (Figure 44) show an excellent AUC score (0.96), an average accuracy (0.496) and a perfect recall score of 1.

Table 65: *Distribution and weight, per class, of Li deposits that were used to model the favourability for lithium mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	5	81
B (large)	10	27
C (medium)	4	9
D (small)	13	3
E (very small)	73	1
Total:	105	

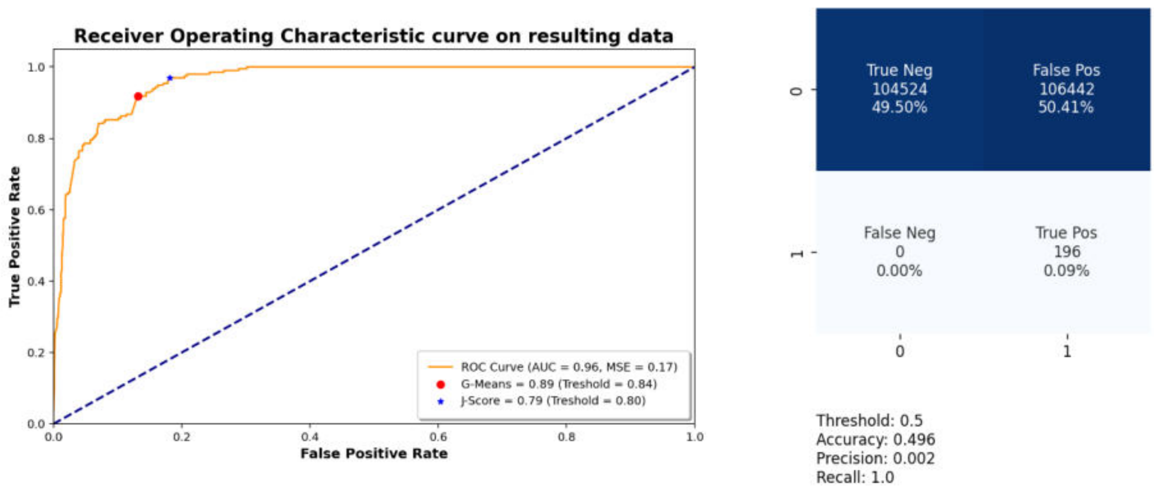


Figure 44: *Performance assessment of the favourability model for lithium mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

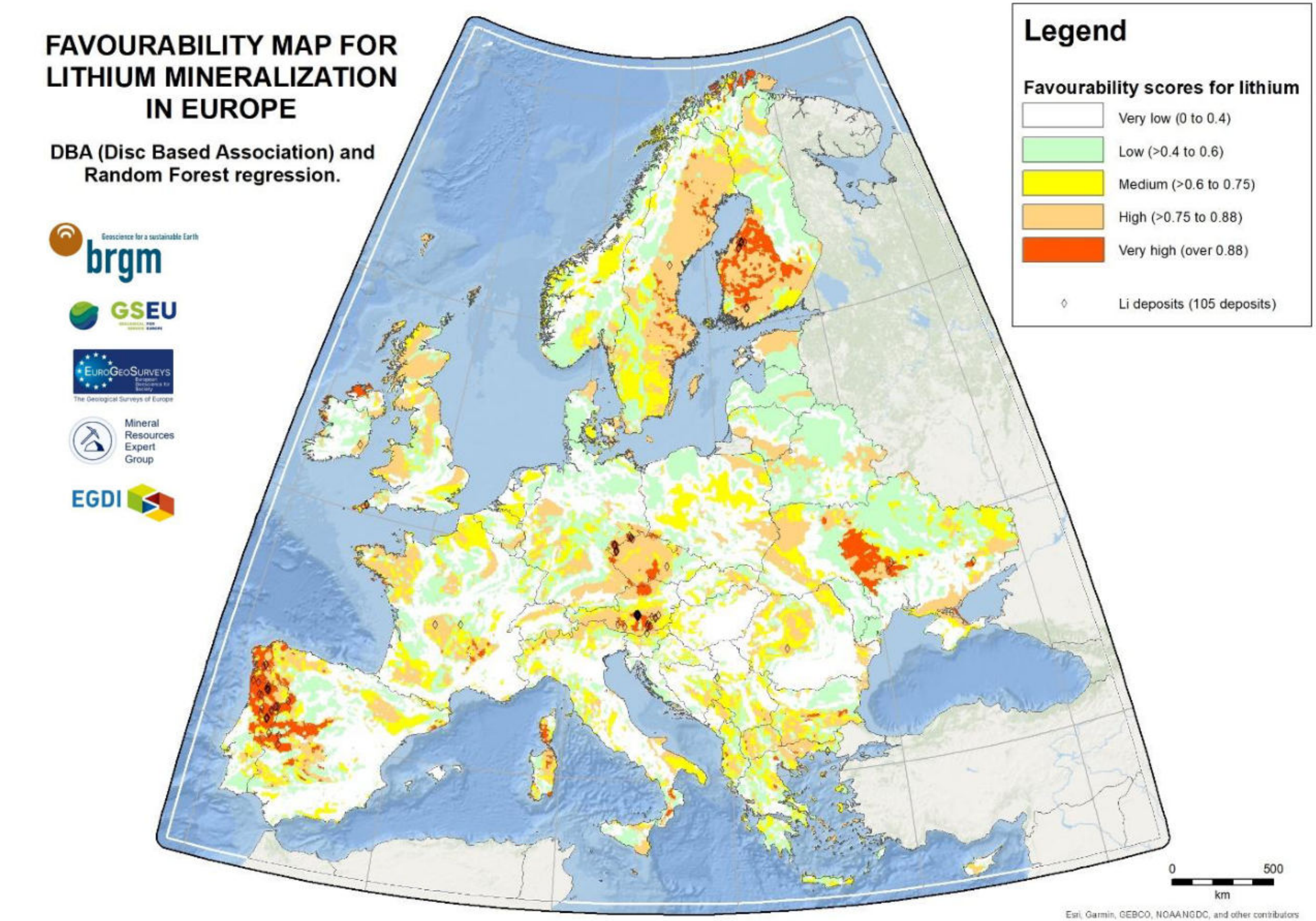


Figure 45: *Favourability map for lithium mineralization in Europe, produced with the DBA & RF method.*

4.3.4. Magnesium (Mg)

The prospectivity map for magnesium was produced with a set of 65 Mg deposits, of class A to E (Table 66). According to the distribution of weights and deposits per class, the model is dominated by B (large) class deposits. The resulting map is presented in Figure 47. The performance metrics of the prospectivity model (Figure 46) show an excellent AUC score (0.96), a relatively low accuracy (0.313) due, as for the Co favourability model, to the large distribution of scores toward higher values (68.69% false positives) and a perfect recall score of 1.

Table 66: *Distribution and weight, per class, of Mg deposits that were used to model the favourability for magnesium mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	6	81
B (large)	31	27
C (medium)	18	9
D (small)	5	3
E (very small)	5	1
Total:	65	

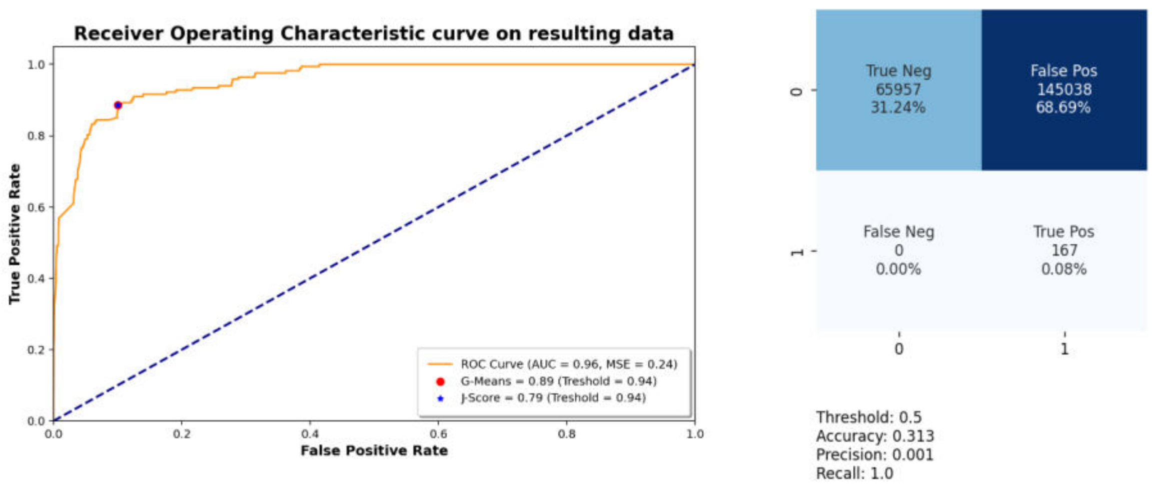


Figure 46: *Performance assessment of the favourability model for magnesium mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

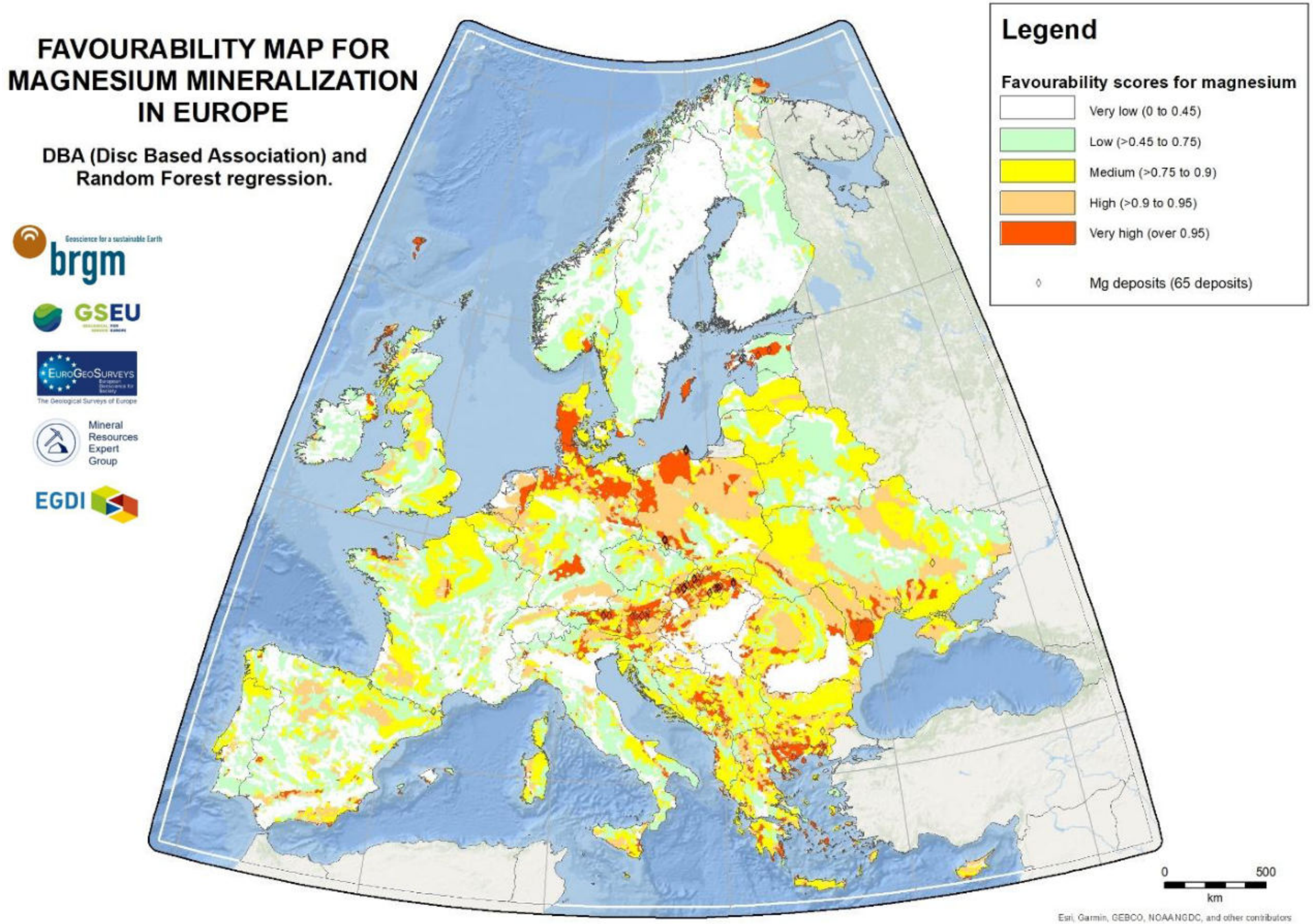


Figure 47: *Favourability map for magnesium mineralization in Europe, produced with the DBA & RF method.*

4.3.5. Manganese (Mn)

The prospectivity map for manganese was produced with a set of 340 Mn deposits, of class A to D (Table 67). 679 class E (very small) deposits were available in the MIN4EU and ProMine databases, but were not used to avoid an oversized learning dataset and a possible dilution of favourability scores over the study area. According to the distribution of weights and deposits per class, the model is dominated by D (small) class deposits. The resulting map is presented in Figure 49. The performance metrics of the prospectivity model (Figure 48) show an excellent AUC score (0.97), a very good accuracy (0.798) and an excellent recall score of 0.979.

Table 67: *Distribution and weight, per class, of Mn deposits that were used to model the favourability for manganese mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	1	64
B (large)	3	16
C (medium)	23	4
D (small)	313	1
E (very small)	0	
Total:	340	

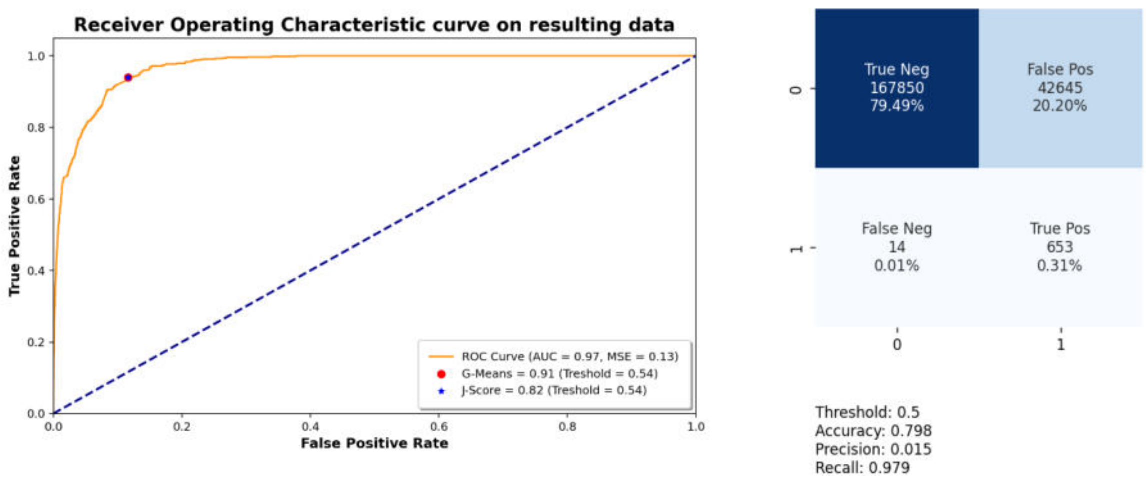


Figure 48: *Performance assessment of the favourability model for manganese mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

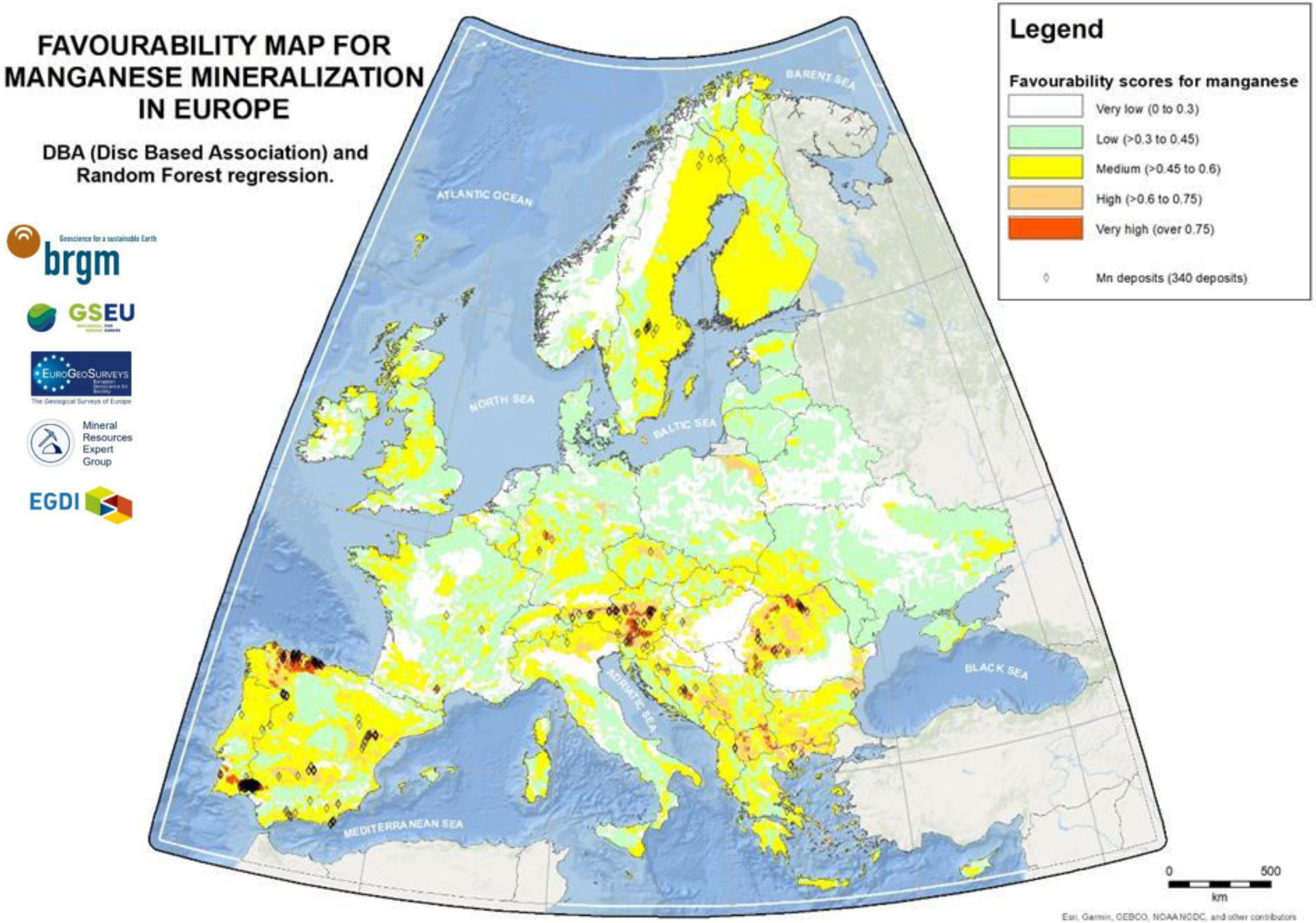


Figure 49: *Favourability map for manganese mineralization in Europe, produced with the DBA & RF method.*

4.3.6. Niobium (Nb)

The prospectivity map for niobium was produced with a set of 50 Nb deposits, of class A to E (Table 68). According to the distribution of weights and deposits per class, the model is dominated by two A (very-large) class deposits. The resulting map is presented in Figure 51. The performance metrics of the prospectivity model (Figure 50) show an excellent AUC score (0.98), a good accuracy (0.68) and a perfect recall score of 1.

Table 68: *Distribution and weight, per class, of Nb deposits that were used to model the favourability for niobium mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	2	81
B (large)	2	27
C (medium)	3	9
D (small)	17	3
E (very small)	26	1
Total:	50	

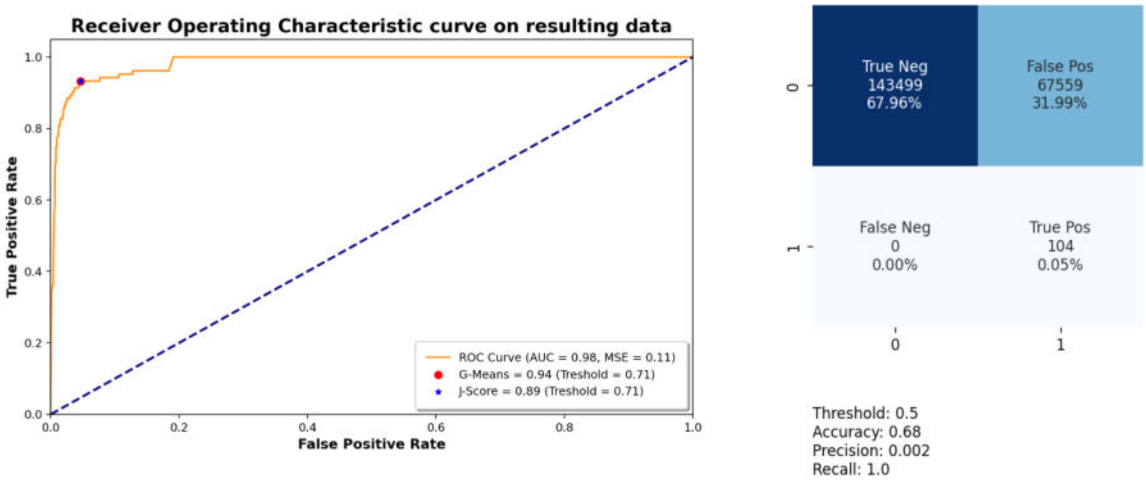


Figure 50: *Performance assessment of the favourability model for niobium mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

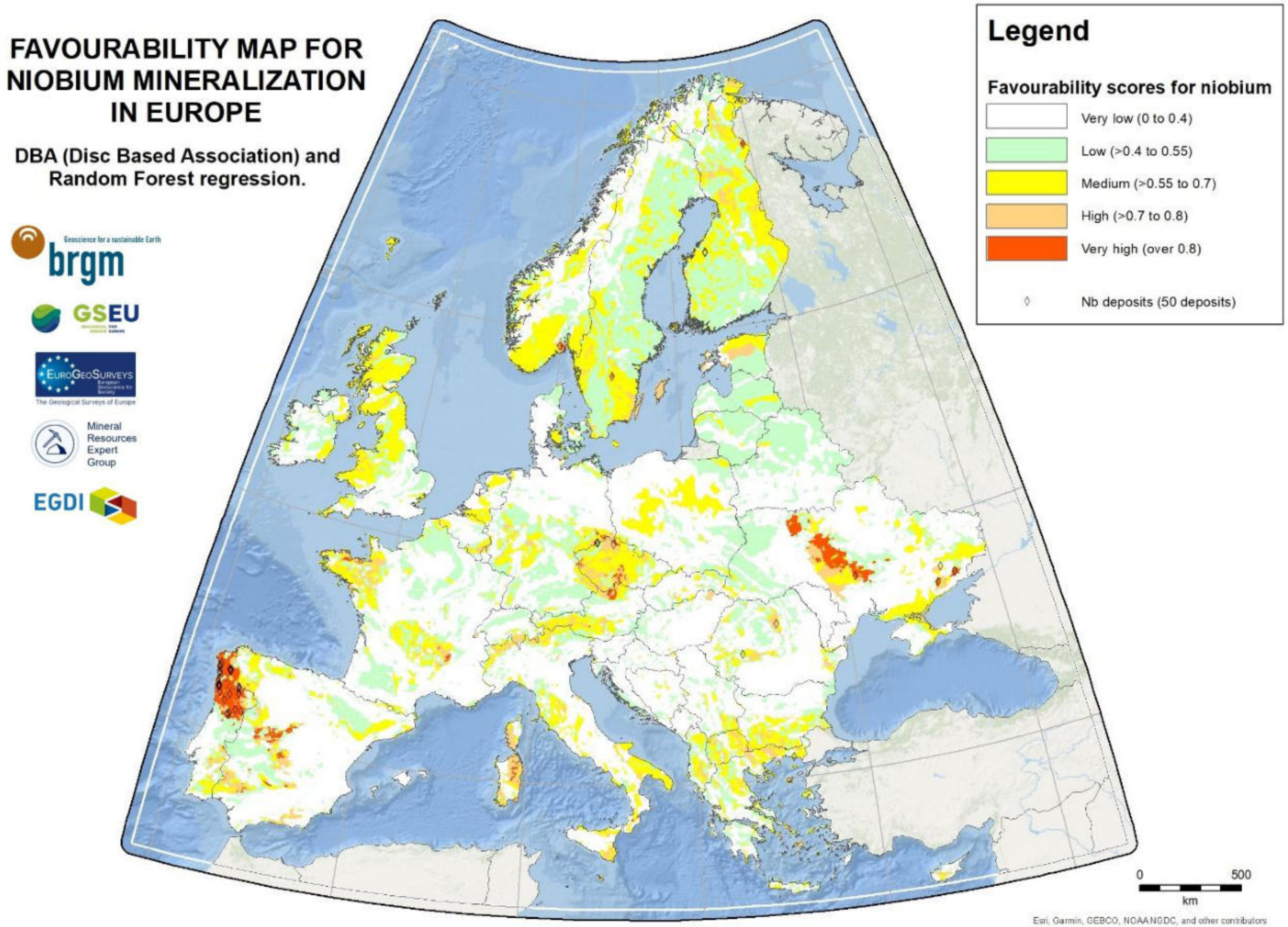


Figure 51: *Favourability map for niobium mineralization in Europe, produced with the DBA & RF method.*

4.3.7. Nickel (Ni)

The prospectivity map for nickel was produced with a set of 319 Ni deposits, of class A to E (Table 69). According to the distribution of weights and deposits per class, the model is dominated by C (medium) and to a lesser degree B (large) class deposits. The resulting map is presented in Figure 53. The performance metrics of the prospectivity model (Figure 52) show a very good AUC score (0.92), an average accuracy (0.447) and a perfect recall score of 1.

Table 69: *Distribution and weight, per class, of Ni deposits that were used to model the favourability for nickel mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	1	81
B (large)	8	27
C (medium)	52	9
D (small)	101	3
E (very small)	157	1
Total:	319	

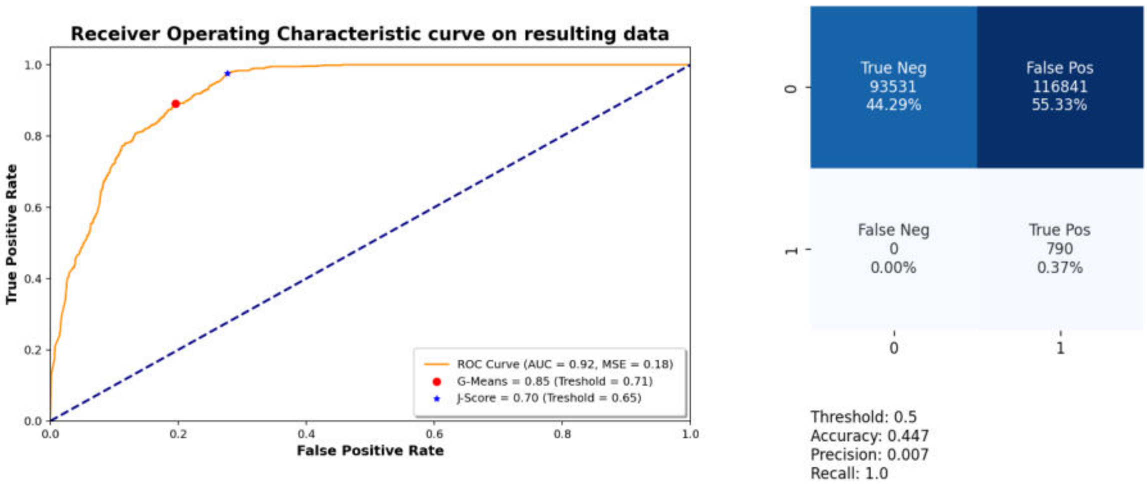


Figure 52: *Performance assessment of the favourability model for nickel mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

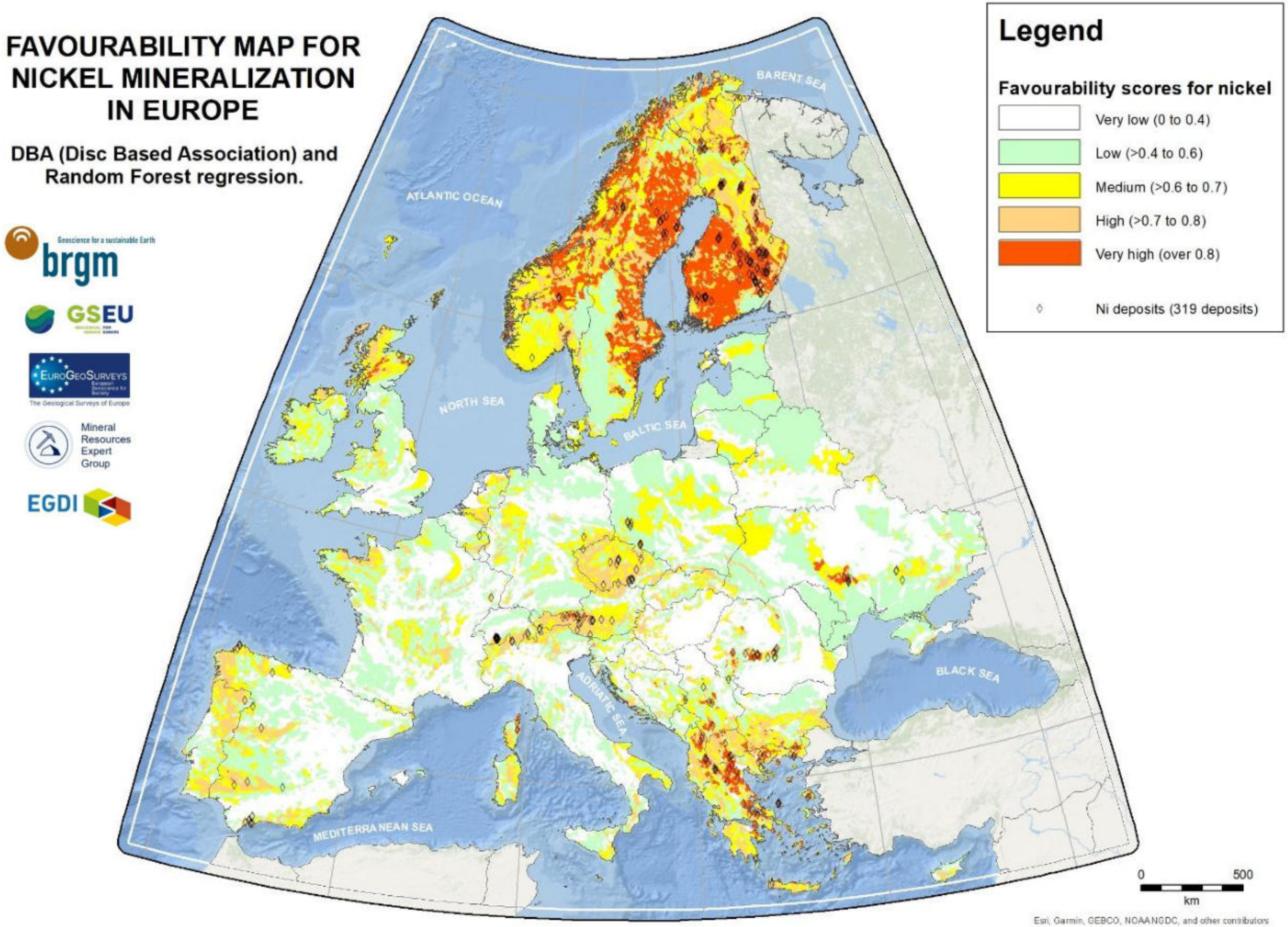


Figure 53: *Favourability map for nickel mineralization in Europe, produced with the DBA & RF method.*

4.3.8. Antimony (Sb)

The prospectivity map for antimony was produced with a set of 107 Sb deposits, of class B to E (Table 70). No class A deposit was identified in the dataset. According to the distribution of weights and deposits per class, the model is dominated by C (medium) and to a lesser degree B (large) class deposits. The resulting map is presented in Figure 55. The performance metrics of the prospectivity model (Figure 54) show an excellent AUC score (0.96), an average accuracy (0.455) and a perfect recall score of 1.

Table 70: *Distribution and weight, per class, of Sb deposits that were used to model the favourability for antimony mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	0	
B (large)	7	64
C (medium)	33	16
D (small)	11	4
E (very small)	56	1
Total:	107	

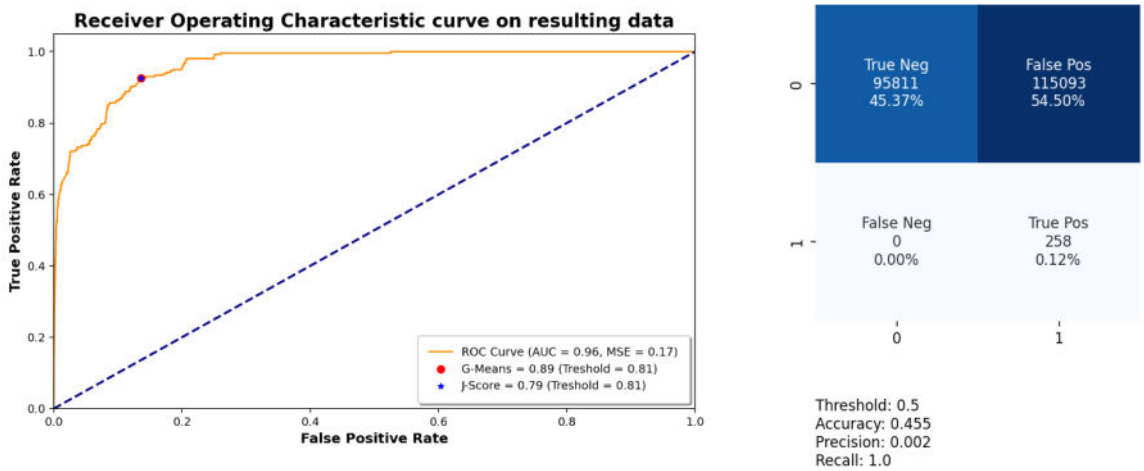


Figure 54: *Performance assessment of the favourability model for antimony mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

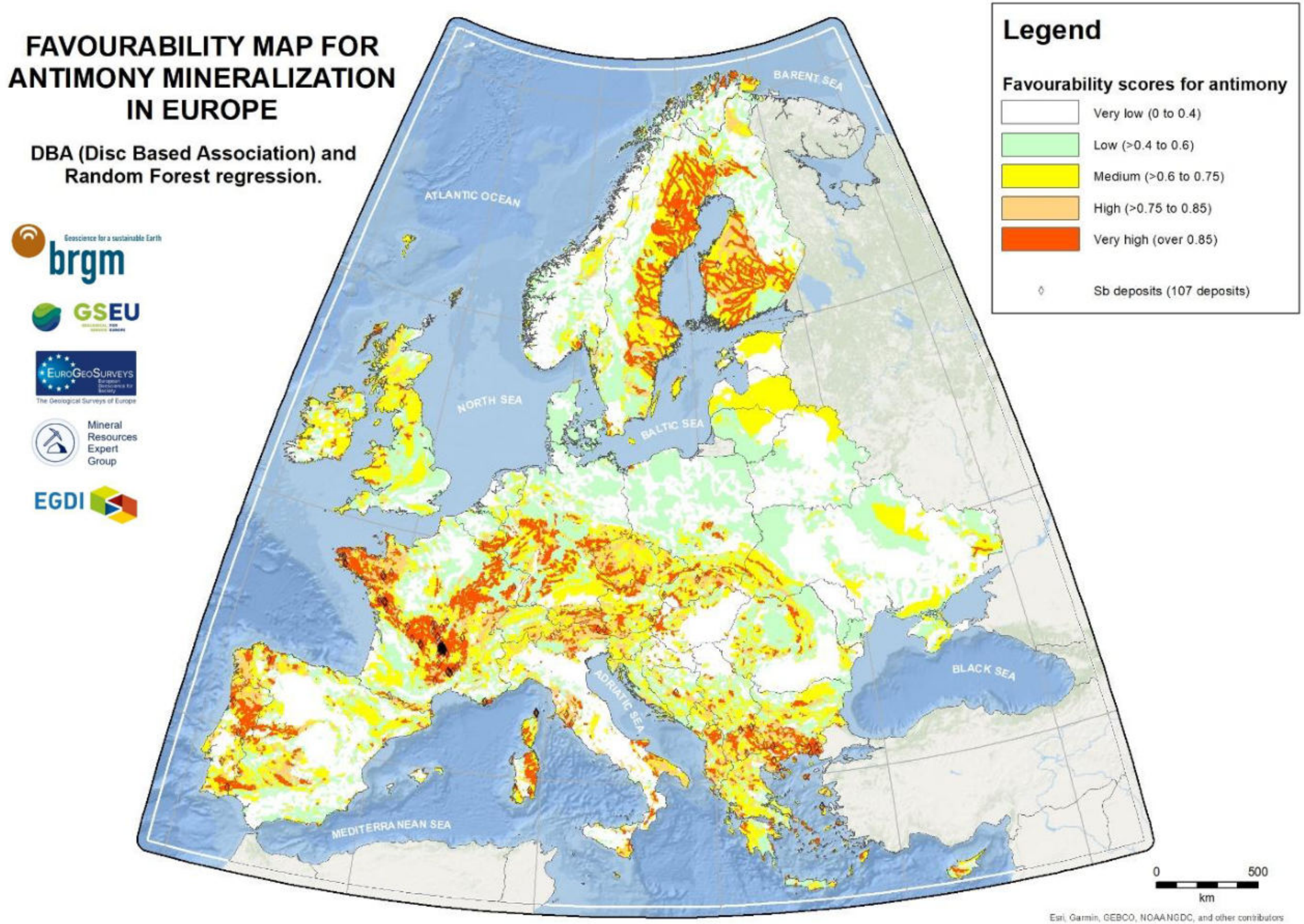


Figure 55: *Favourability map for antimony mineralization in Europe, produced with the DBA & RF method.*

4.3.9. Tantalum (Ta)

The prospectivity map for tantalum was produced with a set of 64 Ni deposits, of class A to E (Table 71). Note that only 6 deposits (classes A to C) were from the GSEU dataset while 58 (classes D and E) were from the MIN4EU and ProMine databases. According to the distribution of weights and deposits per class, the model is dominated by the three A (super-large) class deposits. The resulting map is presented in Figure 57. The performance metrics of the prospectivity model (Figure 56) show an excellent AUC score (0.99), a very good accuracy (0.737) and a perfect recall score of 1.

Table 71: *Distribution and weight, per class, of Ta deposits that were used to model the favourability for tantalum mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	3	81
B (large)	2	27
C (medium)	1	9
D (small)	23	3
E (very small)	35	1
Total:	64	

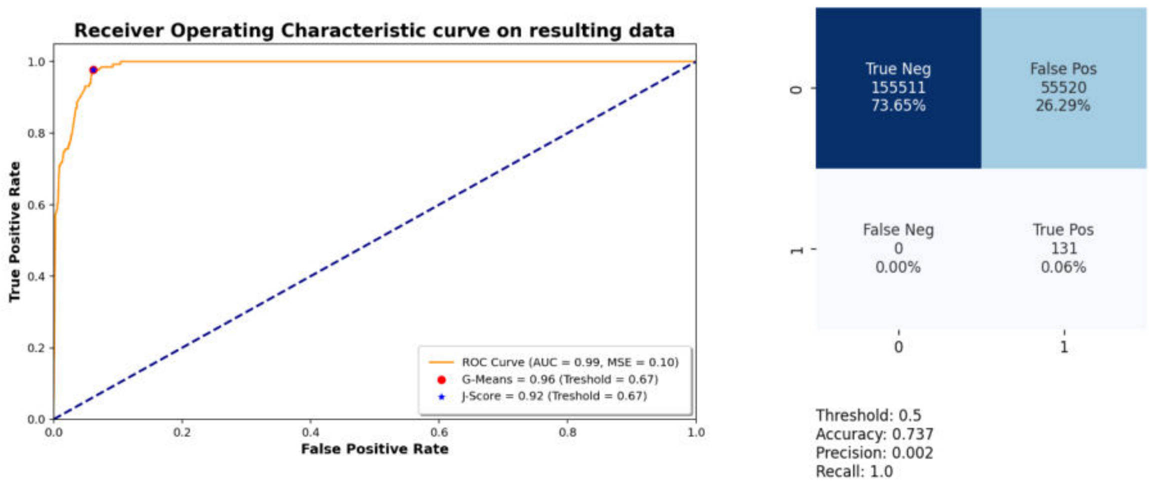


Figure 56: *Performance assessment of the favourability model for tantalum mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

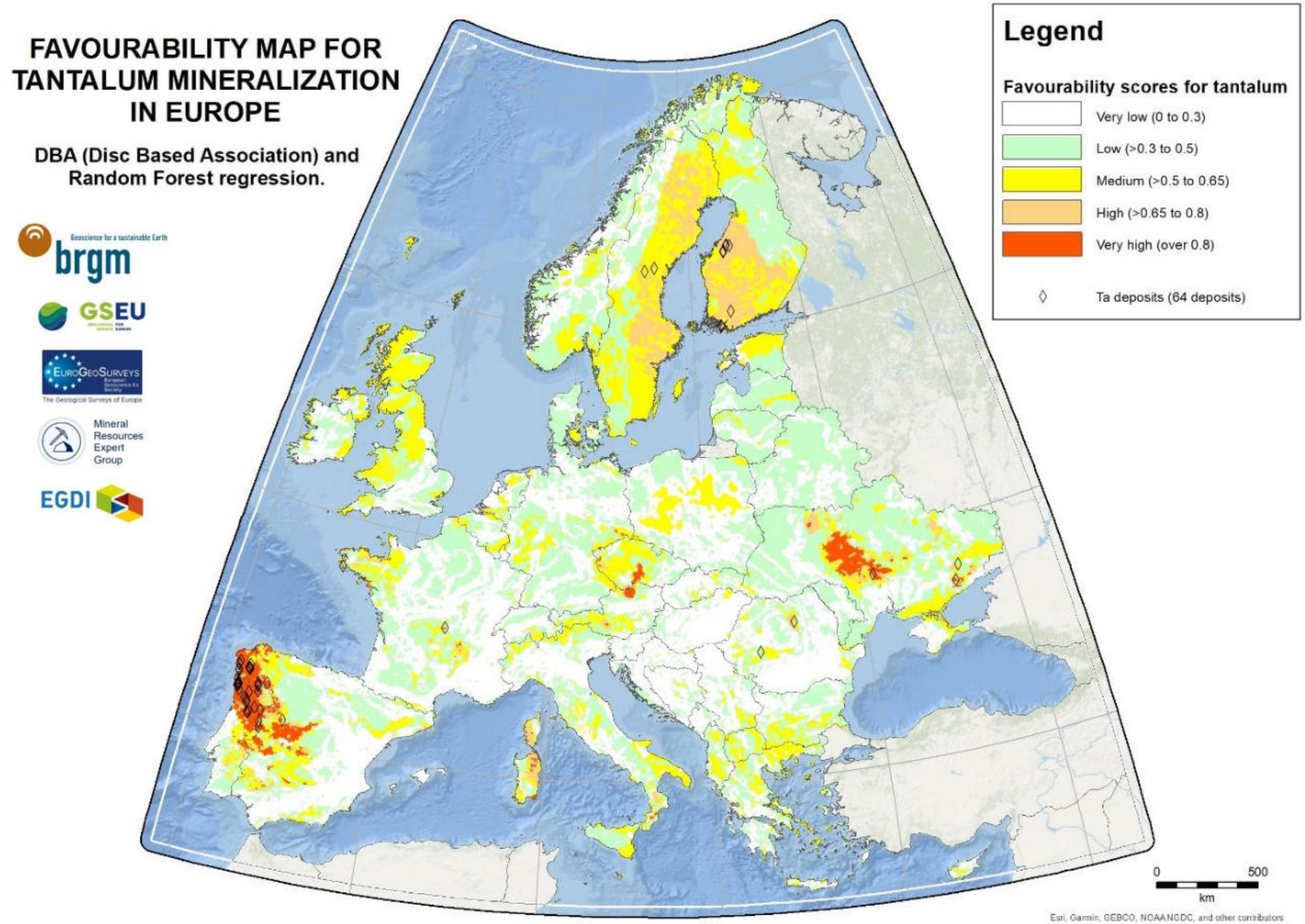


Figure 57: *Favourability map for tantalum mineralization in Europe, produced with the DBA & RF method.*

4.3.10. Vanadium (V)

The prospectivity map for vanadium was produced with a set of 80 V deposits, of class A to E (Table 72). According to the distribution of weights and deposits per class, the model is dominated by B (large) and to a lesser degree C (medium) class deposits. The resulting map is presented in Figure 59. The performance metrics of the prospectivity model (Figure 58) show a very good AUC score (0.93), an average accuracy (0.463) and a perfect recall score of 1.

Table 72: *Distribution and weight, per class, of V deposits that were used to model the favourability for vanadium mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	1	81
B (large)	7	27
C (medium)	17	9
D (small)	39	3
E (very small)	16	1
Total:	80	

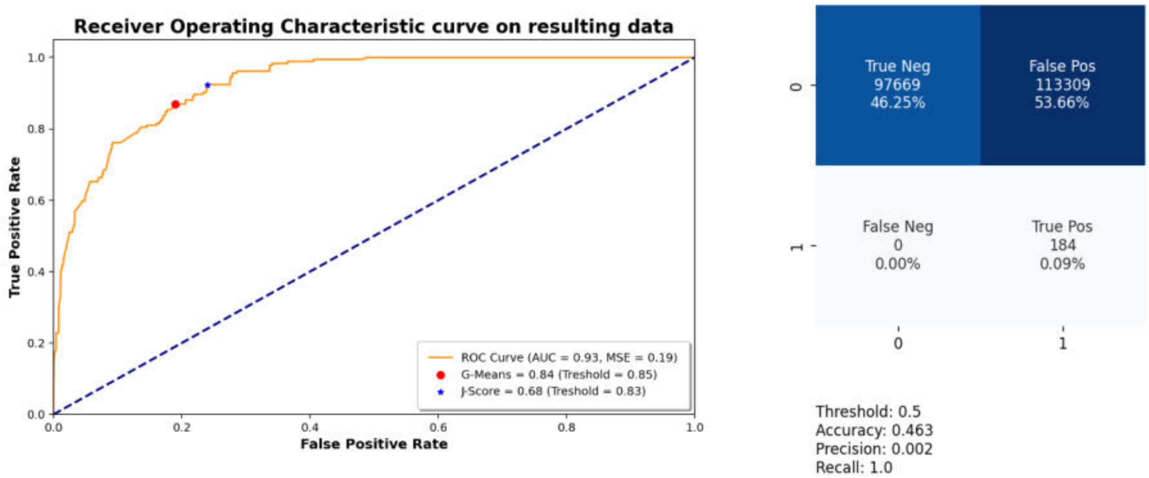


Figure 58: *Performance assessment of the favourability model for vanadium mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

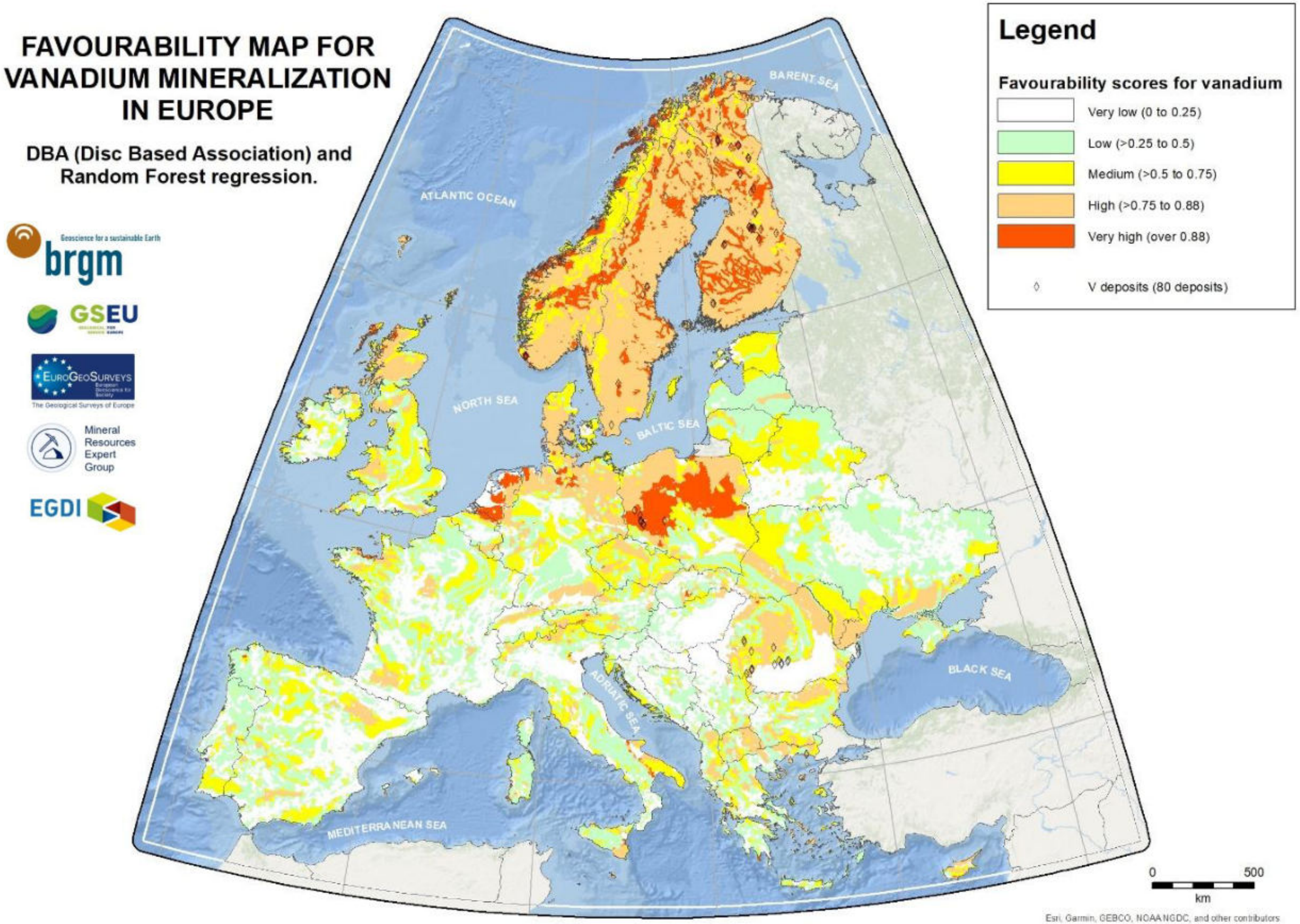


Figure 59: *Favourability map for vanadium mineralization in Europe, produced with the DBA & RF method.*

4.3.11. Tungsten (W)

The prospectivity map for tungsten was produced with a set of 317 W deposits, of class A to D (Table 73). 553 class E (very small) deposits were available in the MIN4EU and ProMine databases, but were not used to avoid an oversized learning dataset and a possible dilution of favourability scores over the study area. According to the distribution of weights and deposits per class, the model is dominated by D (small) class deposits. The resulting map is presented in Figure 61. The performance metrics of the prospectivity model (Figure 60) show an excellent AUC score (0.98), a very good accuracy (0.863) and an excellent recall score of 0.967.

Table 73: *Distribution and weight, per class, of W deposits that were used to model the favourability for tungsten mineralization in Europe.*

Class of deposits	Number of deposits	Weight per deposit
A (super large)	3	64
B (large)	5	16
C (medium)	29	4
D (small)	280	1
E (very small)	0	
Total:	317	

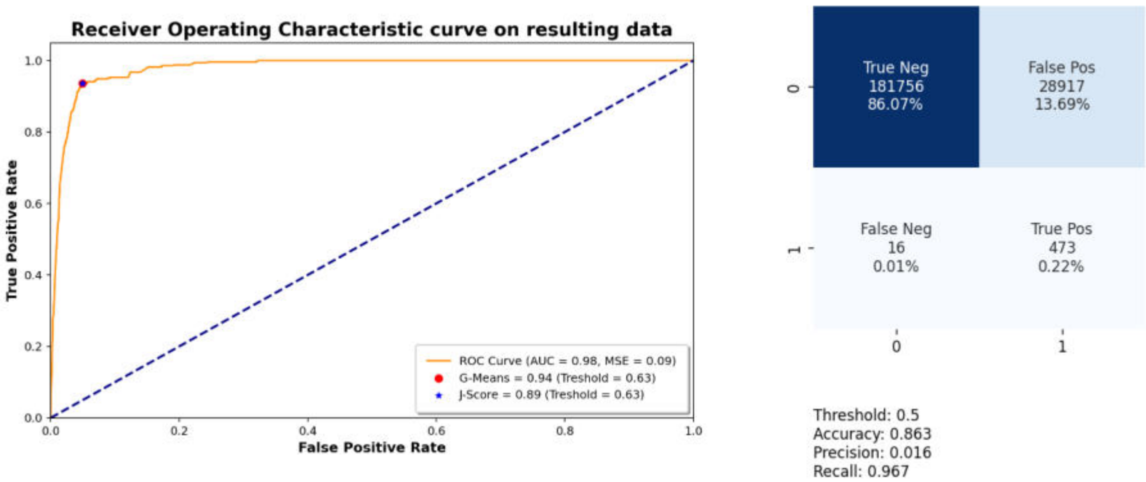


Figure 60: *Performance assessment of the favourability model for tungsten mineralization in Europe; left: ROC curve and AUC score; right: confusion matrix, accuracy, precision and recall scores.*

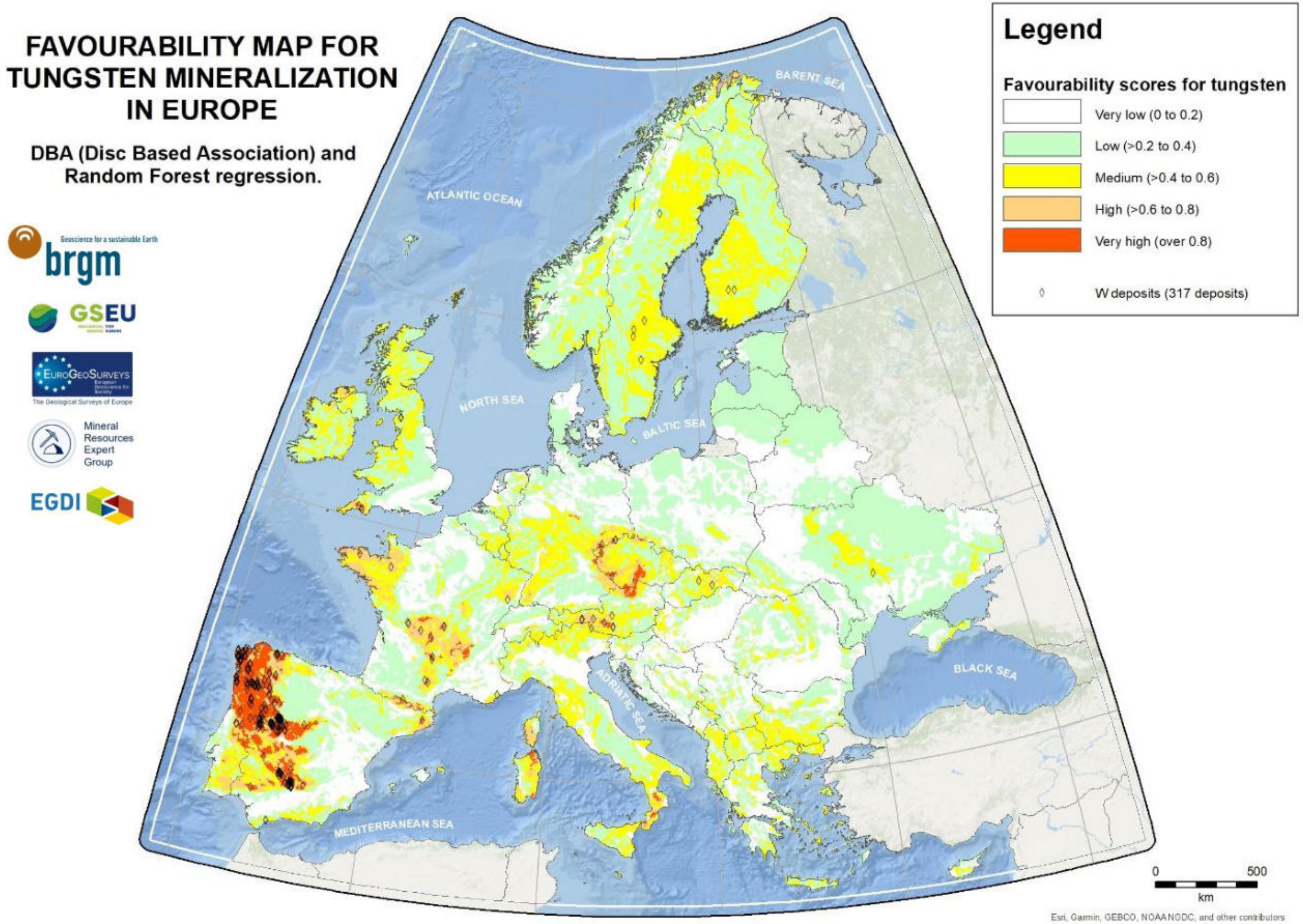


Figure 61: *Favourability map for tungsten mineralization in Europe, produced with the DBA & RF method.*

4.3.12. Concluding Remarks on Prospectivity Maps

The favourability maps that are presented in the previous sections are valuable inputs to identify regions in Europe that are most favourable for the discovery of new deposits. They represent a great step forward compared to a similar work that was previously done by the GeoERA-FRAME project (Bertrand et al., 2021).

The first significant progress is on the quality of the data. If the GeoERA-FRAME project already made a big progress on the compilation, harmonisation and update of data, it was on a limited number of commodities that were cobalt, lithium, natural graphite, phosphate rocks, niobium, tantalum and rare earth elements. The GSEU project developed this effort to most critical raw materials from the latest list of the European Commission (2023). A consequence is that in the future, additional prospectivity maps at the scale of Europe can be added to the 11 that are presented in this report.

The second significant progress of this work is on the methodology that was used to produce the prospectivity maps. In the GeoERA-FRAME project, the CBA method (Tourlière et al., 2015) was used, with the limitations that are detailed in the methodology section of this report. For the present study, we have used the DBA & RF method (Vella, 2022) that is an evolution that solves most of the limitations inherent to the CBA. As a consequence, the prospectivity models presented here are more detailed and performant. More specifically, the technical benefits are:

- The DBA allows a better resolution of the prospectivity model (5x5 km cell size in the present study versus 10x10 km in the GeoERA-FRAME prospectivity maps). This resolution remains coarse but it is in the order of the area size considered for an exploration permit and we hope to improve it in the future with parallel or cluster computing
- The RF regression provides better performance than the calculation of favourability scores of the CBA; this is confirmed for instance by the AUC score that were comprised between 0.74 and 0.90 in the GeoERA-FRAME prospectivity maps (Bertrand et al., 2021) while they are comprised between 0.91 and 0.99 in the present study
- Only lithology polygons were used as evidential layer in the GeoERA-FRAME prospectivity maps (Bertrand et al., 2021) while lithology polygons and fault lines were used in the present study; another progress of the DBA method (Vella, 2022) is that it can process continuous data such as airborne geophysics; we have not used such data because we do not have complete coverage at the scale of Europe, but it is an improvement that could be done at regional to local scales, depending on data availability
- Deposits in the present study were weighted based on their class, while weighting was not used for the GeoERA-FRAME maps; the log3 to log5 weighting that was used herein is in our opinion a good compromise between a linear weighting that would probably penalize larger deposits and a log10 weighting that may turn smaller deposits negligible
- Finally, the Python DBA and RF algorithms that were used in the present study (Vella, 2022) were more efficient than those used by the GeoERA-FRAME project (Bertrand et al., 2021), allowing to compute the model in less than 2 hours versus approximately 30 hours previously.

Despite the technical progress prospectivity maps presented herein made from previous studies, their scale remains too coarse to directly guide exploration campaigns. Still, they highlight regions that are most favourable for new discoveries. As such, they are useful for policymaking and land-use planning at national to European scale. They are also useful to the mining industry by highlighting areas where mineral exploration should be targeted in priority.

The prospectivity maps presented herein are a large-scale assessment of pan-European favourability for selected critical raw materials. This work should be developed in two directions:

1. First by producing pan-European favourability maps for additional commodities of the 2023 EU list of CRM (European Commission, 2023); this will be done in the coming 24 months and will be presented in the version 2 of the present report that is due by October 2026
2. Secondly by producing more accurate favourability maps, at regional scale and with higher resolution, and based on additional datasets (e.g. airborne geophysics, geochemistry, etc.).

Finally, we must keep in mind that **our prospectivity maps assess a geological favourability. They do not integrate social, environmental and economic criteria**. As such, they assess the favourability for a geological potential and do not prejudge any mining project in any area. Environmental, social and economic aspects are crucial and should be considered from the early phases of any potential mining project.

5. Current knowledge and data gaps

This data collection process revealed some disparities in data completeness and quality across Europe, as listed below. Countries collect data for different national and regional end uses. The ways in which this data is described and organized differs due to different geological contexts, geoscientific practices and traditions, and mineral legislation.

- Reporting of metallic vs. non-metallic commodities
  Metallic minerals contain metals structurally in their crystal lattice (e.g. copper, cobalt, nickel, REE, lithium, etc…). On the other hand, industrial minerals and rocks are commodities that are neither metallic nor energy related, and often valued for their physical or chemical properties. The CRM list (European Commission, 2023) contains minerals from both categories. Besides having different end-uses, there are some key differences between them related to the legal and regulatory frameworks for their extraction. Both types of extraction are subject to strict regulations by government agencies, but they typically differ in terms of how resource tracking and production monitoring are handled. In practice, mines, especially those extracting precious metals and high-value minerals, are subject to high-level regulation and comprehensive tracking, making it easier for regulatory bodies (and GSOs) to monitor mining production, understand national resource availability, and ensure compliance with reporting, environmental and safety standards. For industrial minerals, regulatory oversight is generally lighter, especially for small operations, meaning tracking of production is often less precise or consistent. An additional hurdle is that these differences vary depending on the country. The lack of harmonisation of these regulations within Europe makes the compilation of transnational data more challenging. In this report, the assessment of national-level data on aggregate resources for non-metallic CRM (bauxite, baryte, boron minerals, feldspar, fluorspar, graphite, magnesite, phosphorous minerals, strontium minerals) is generally considered less reliable compared to other commodities.

- Primary commodities vs. by-products resource estimates
  Some commodities can be of economic interest by themselves (primary products), while others constitute by-products that are recovered during mineral beneficiation or further downstream supply chain steps (e.g. Nassar et al., 2015). Primary products resources can be evaluated relatively straightforwardly during exploration activities. This is generally the case in Europe for the following CRM: bauxite, baryte, boron minerals, coking coal, copper, feldspar, fluorspar, lithium, magnesium, manganese, natural graphite, nickel, phosphate rocks, REE, silicon metal, titanium metal and tungsten. In contrast, by-products may contribute additional market value to a mining project, but their concentrations have typically not been investigated in the past, or on a more regional scale, so often there is no data available on their abundance and distribution. This key concept of interdependence (or metal companionality) makes resource estimation of by-products challenging, as their availability cannot be estimated independently of associated primary mineral production. Resource potential is thus largely based on the identification of favourable geological contexts rather than precise quantification. This is the case in Europe for the CRM gallium, germanium, hafnium and scandium. It should also be noted that metal associations vary greatly depending on the geological context, and that these concepts evolve in practice with the prevailing economic conditions. For example, while germanium is most often recovered as a by-product of the processing of zinc ores, it has historically been recovered as the main product at the Saint-Salvy mine in France.

- Resource tracking and production monitoring

Each European country has its own regulatory framework and data collection practices, which vary widely in scope, accuracy, and frequency of updates. In some countries, regulatory bodies (i.e. mining authorities) are not obligated or inclined to share data with GSOs, either due to regulatory barriers or a simple lack of coordinated processes. Furthermore, differences in the legal definitions and classifications of resources – like the distinction between metallic and industrial minerals – compound the problem, as these materials may be reported under different categories or not tracked at all. GSOs track updates in mining activity and output often through the reviewing of publicly disclosed annual or quarterly reports. A handful of GSOs have set up a monitoring procedure to maintain a continuous (annual) update of their national inventories. The acquisition of resources and reserves data and monitoring of countrywide mining activity can be a time-consuming and resource-intensive process. The majority of GSOs have reported that they do not have such procedure in place, and data at national-level is collected on an ad hoc basis.

- Digitalization and reporting of historic data
  Many European countries have rich mining histories, with several of the large mineral deposits listed in this report having undergone extraction for centuries if not more. Records of past mining activity are often fragmented, stored in varying formats, and sometimes kept in archives with limited access. Older data may exist in physical form, such as handwritten documents, maps, or ledgers, which are often difficult to digitize accurately due to potential degradation, outdated terminology, or non-standardized measurements. Even when data is digitized, discrepancies in classification methods, units, and quality standards can hinder effective aggregation. This is a common issue across Europe. Due to data unavailability and/or unreliability, past production is either partial or unaccounted for. For this reason, the total tonnage endowment values provided in section 3 should be regarded as lower end estimations.

  It is worth mentioning another aspect related to the handling of historical data. In several former Soviet states, it was common practice for mining companies and geological agencies to inflate reported mineral resources. This was driven by political and economic pressures from the central government, which sought to demonstrate the Soviet Union's industrial and natural resource strength. As part of centrally planned economies, these states were often incentivized to exaggerate resource estimates to meet production quotas, attract investment, or achieve political objectives. Inflated data served multiple purposes: it helped secure continued government funding, justified large-scale industrial projects, and allowed local authorities to claim success in fulfilling the Soviet state's goals. The focus was on fulfilling political targets rather than accurately assessing or managing resources, which led to unreliable reporting on reserves and production potential. In some cases, geological data was manipulated by including resources that were not economically viable or by overstating accessible reserves. This legacy of inaccurate data has had lasting effects on resource management and investment decisions in the post-Soviet era. Modern regulatory and GSOs in these countries are often tasked with verifying and reassessing old data to provide accurate estimates for potential investors and international bodies, a time-consuming and costly process given the sometimes significant discrepancies with past reports.

- Data confidentiality
  Several countries withhold their mining production and resource data to protect strategic or economic interests. The confidentiality of mining data complicates the work of GSOs, policymakers on the European level, and international bodies that aim to compile a unified, transparent resource database, leading to potential gaps in understanding Europe's true mineral resource base. This lack of transparency can hinder investment, slow down collaborative efforts in resource management, and make it harder to anticipate and address supply risks for critical minerals

essential to Europe's industries and green energy initiatives. Confidential data makes up 18% of the deposits reported in this assessment. Austria, Czech Republic, Slovakia, Romania, Ukraine and Italy either wholly or partially withhold their resource and mining production data.

- Data harmonisation

  Harmonising reporting standards for mineral resources across Europe is challenging due to the diversity of reporting systems, economic priorities, and historical practices among countries. Currently, various classification frameworks are in use, with some of the most widely recognized being the CRIRSCO Template, which serves as the basis for the JORC (Australasian), PERC (European), and NI 43-101 (Canadian) standards. The use of the UNFC, which integrates environmental and social considerations alongside resource classification, is being increasingly promoted. While many Western European countries have adopted CRIRSCO-aligned standards, former Soviet states still often rely on the Soviet-style GKZ system (State Commission on Mineral Resources), which includes reserves that may not be economically viable by Western standards. Additionally, some countries including Germany, France, Poland and Estonia maintain national standards that may not fully align with international frameworks. This lack of harmonisation complicates efforts to track resources effectively. Solutions for standardization include promoting the adoption of CRIRSCO-aligned frameworks, which are widely recognized by the international mining community, and developing a hybrid framework that bridges existing systems while addressing European-specific goals.

6. CRM in Mining Waste

Europe has, in many of its regions, a legacy of raw materials extraction and thus substantial amounts of extractive waste on closed facilities. This extractive waste, coming from extraction and processing of mineral ores, has generally not been analysed for CRM potential before due to their only recent rise in economic importance, and despite mining waste being one of the largest waste streams in the EU. Mining waste sites may include materials such as topsoil overburden (which have been removed to gain access to mineral resources, for modern operations this usually is put back as part of the remediation after closure), as well as waste rock and tailings (after the extraction of the valuable mineral).

The recovery of CRM from extractive waste facilities has the potential to create economic value and employment in historical mining regions, which are often affected by deindustrialisation and decline. Recovering CRM from mining waste offers significant environmental and energy-saving advantages. By utilizing waste as a secondary resource, the overall volume of mining residue is reduced, mitigating its ecological footprint. Additionally, much of the energy-intensive crushing work required for primary extraction has already been completed during initial processing, leading to lower energy consumption in CRM recovery. However, this is not without challenges. Mining waste typically undergo chemical and physical alterations over time including oxidation and weathering, and commodities often are often altered and oxidised at various stages, which can complicate the recovery process. These changes may necessitate more complex and specialized treatment techniques, increasing the technical and economic hurdles of reclaiming valuable elements from such secondary sources.

The lack of attention to, and knowledge on CRM content, especially on closed waste facilities, constitutes a key barrier to increased use of CRM from extractive waste. However, work is ongoing at different levels to remediate this issue. GSOs that are part of the GSEU consortium work in tight cooperation with the EU funded FutuRaM project that coordinates the collection of mining waste data. Furthermore, since the implementation of the CRM Act in May 2024, EU Member States are mandated to provide information on their extractive waste facilities (Article 27 of the CRM Act). The Act identifies two main factors for mining wastes: obligations referring to operators (current mining activity) and obligations to Member States concerning historical or legacy sites.

Current knowledge about mining waste in Europe results from several EU funded research projects that aimed to collect and structure historical mining waste data in a pan-European database based on national inventories. The ProMine project (2009-2013) has developed the first pan-European database for mining waste (Cassard et al., 2015), including general information about mines, main commodities contained and for certain sites, tonnage estimates. The ProMine Anthropogenic Concentrations (AC) database related to mining and metallurgical industries contained approximately 3400 records of waste sites, including mine wastes and unprocessed products (e.g. run-of-mine ore, unprocessed ore stockpiles, mine waste dumps, barren overburden), ore processing wastes (e.g. cobbing waste, wash tailings, flotation tailings, leach residues, magnetic-separation tailings) and treatment waste (e.g. smelter wastes, flue dusts, roasting residues, chemical treatment wastes, leach tailings, ashes, cocking plant residues, and more). The ProMine AC data set is available on the EGDI portal through a web service. Following ProMine, data collection of mining waste data at European level continued with the MIN4EU database, which will be made available on EGDI and updated as research progresses. The mining waste data model architecture was further developed under the ProSUM project. MIN4EU is currently the reference database for mineral resources in Europe including mining waste. This database contains information at site level (mining waste deposit), if available, including waste type, composition and volume.

At the start of the GSEU and FutuRaM projects in the fall of 2022, the situation in terms of mining waste data collection was such that 14 data providers from 12 countries had delivered mining waste data. However, only 109 of those records, all located in Portugal, contained ore grade measurements. The other records only contained basic information such as name, location, waste type and in some cases volume estimates. Since 2022, several additional countries have released additional mining waste data, which either has or is in the process of being transferred to the central MIN4EU database. This is the case for Spain (Rosario-Beltré et al., 2023), some Balkan countries (during the RESEERVE project; Sajn et al., 2022) and Portugal (Oliveira et al., 2024). In parallel, within the framework of FutuRaM and GSEU, several workshops were organised with a dual purpose: training of GSOs members in the use of MIN4EU as main data repository, and collection of new mining waste data.

At present, a full European evaluation of the CRM potential in mining waste is a premature undertaking due to the paucity of high-quality data for CRM potential assessment in historical mining waste. There are however growing efforts to characterize old tailings and other deposits in terms of potential valuable CRM. Recent noteworthy initiatives include the ones in Spain, the Balkan countries and Portugal referenced above, the commissioning by the Swedish Geological Survey of a methodology report on best practices for surveying and sampling of mining wastes (Sädbom and Bäckström, 2018), and ongoing programs initiated in France and Italy for the characterization of these sites. Notably, these are fully aligned with the CRM Act article 27, which mandates Member States of the EU to publish an inventory of historical mining wastes and their CRM content.

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8. Annex I – Consortium Partners

Consortium partners			
	Partner Name	**Acronym**	**Country**
1	EuroGeoSurveys	EGS	Belgium
2	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek	TNO	Netherlands
3	Sherbimi Gjeologjik Shqiptar	AGS	Albania
4	Vlaamse Gewest	VLO	Belgium
5	Bureau de Recherches Géologiques et Minières	BRGM	France
6	Ministry for Finance and Employment	MFE	Malta
7	Hrvatski Geološki Institut	HGI-CGS	Croatia
8	Institut Royal des Sciences Naturelles de Belgique	RBINS-GSB	Belgium
9	Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy	PGI-NRI	Poland
10	Institut Cartogràfic i Geològic de Catalunya	ICGC	Spain
11	Česká Geologická Služba	CGS	Czechia
12	Department of Environment, Climate and Communications - Geological Survey Ireland	GSI	Ireland
13	Agencia Estatal Consejo Superior de Investigaciones Cientificas	CSIC-IGME	Spain
14	Bundesanstalt für Geowissenschaften und Rohstoffe	BGR	Germany
15	Geološki zavod Slovenije	GeoZS	Slovenia
16	Federalni Zavod za Geologiju Sarajevo	FZZG	Bosnia and Herzegovina
17	Istituto Superiore per la Protezione e la Ricerca Ambientale	ISPRA	Italy
18	Regione Umbria	-	Italy

19	State Research and Development Enterprise State Information Geological Fund of Ukraine	GIU	Ukraine
20	Institute of Geological Sciences National Academy of Sciences of Ukraine	IGS	Ukraine
21	M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of NAS of Ukraine	IGMOF	Ukraine
22	Ukrainian Association of Geologists	UAG	Ukraine
23	Geologian Tutkimuskeskus	GTK	Finland
24	Geological Survey of Serbia	GZS	Serbia
25	Ministry of Agriculture, Rural Development and Environment of Cyprus	GSD	Cyprus
26	Norges Geologiske Undersøkelse	NGU	Norway
27	Latvijas Vides, ģeoloģijas un meteoroloģijas centrs SIA	LVGMC	Latvia
28	Sveriges Geologiska Undersökning	SGU	Sweden
29	Geological Survey of Denmark and Greenland	GEUS	Denmark
30	Institutul Geologic al României	IGR	Romania
31	Szabályozott Tevékenységek Felügyeleti Hatósága	SZTFH	Hungary
32	Eidgenössisches Departement für Verteidigung, Bevölkerungsschutz und Sport	VBS (DDPS)	Switzerland
33	Elliniki Archi Geologikon kai Metalleftikon Erevnon	HSGME	Greece
34	Laboratório Nacional de Energia e Geología I.P.	LNEG	Portugal
35	Lietuvos Geologijos Tarnyba prie Aplinkos Ministerijos	LGT	Lithuania
36	Geologische Bundesanstalt	GBA	Austria
37	Service Géologique de Luxembourg	SGL	Luxembourg
38	Eesti Geoloogiateenistus	EGT	Estonia

39	Štátny Geologický ústav Dionýza Štúra	SGUDS	Slovakia
40	Íslenskar Orkurannsóknir	ISOR	Iceland
41	Instituto Português do Mar e da Atmosfera	IPMA	Portugal
42	Jarðfeingi	Jardfeingi	Faroe Islands
43	Regierungspräsidium Freiburg	LGRB	Germany
44	Geologischer Dienst Nordrhein-Westfalen	GD NRW	Germany
45	Landesamt für Geologie und Bergwesen Sachsen-Anhalt	LfU	Germany
46	Vlaamse Milieumaatschappij	VMM	Belgium
47	Norwegian Petroleum Directorate	NPD	Norway
48	United Kingdom Research and Innovation - British Geological Survey	UKRI-BGS	UK

9. Annex II – Lexicons for Resource Category

Table 74: *Lexicon for Resource category. This corresponds to the ResourceCategoryType code list from the MIN4EU database.*

indicatedAndInferredMineralResource
indicatedMineralResource
inferredMineralResource
measuredAndIndicatedMineralResource
measuredIndicatedAndInferredMineralResource
measuredMineralResource
(RUS)A
(RUS)A+B
(RUS)B
(RUS)C1
(RUS)C2
(RUS)P1
(RUS)P2
(RUS)P3
anticipatedEconomicResourcesA+B
anticipatedEconomicResourcesC1
anticipatedEconomicResourcesC2
CategoryA
CategoryB
CategoryC
historicResourceEstimate
verified(Z1)
anticipated(Z3)
economicExploredResources
economicProspectedResources
potentiallyEconomicResources
poorlyDocumented

Table 75: *Lexicon for Resources/reserves classification method. This corresponds to the ClassificationMethodUsedType code list from the MIN4EU database.*

CIMstandards
CRIRSCOCode
FRBstandard
historicEstimate
IIMChCode
IMMReportingCode
JORCCode
NationalReportingCode
NI43-101
nonCompliantExplorationEstimate
nonCompliantReserveEstimate
nonCompliantResourceEstimate
PERCCode
PolishClassification
RussianNAENCode
SAMRECCode
SAMVALCode
SECGuide
SMEGuide
UNFCCode
USGS_Circular_831_of_1980

Table 76: *Lexicon for Reserve category. This corresponds to the ReserveCategoryType code list from the MIN4EU database.*

provedOreReserves
provedAndProbableOreReserves
probableOreReserves
(RUS)A
(RUS)A+B
(RUS)B
(RUS)C1
(RUS)C2
(RUS)OffBalance
demonstatredMeasuredReserves
demonstratedIndicatedReserves
demonstratedMeasuredIndicatedReserves
demonstratedMeasuredMarginalReserves
inferredMarginalReserves
inferredReserves
documentedReserves
economicExplored
economicProspected
historicReserveEstimate
inaccessibleDocumentation
mineableReservesA+B
mineableReservesC1
mineableReservesC2
verified(Z1)
probable(Z2)
anticipated(Z3)

Table 77: *Lexicon for mine status. This corresponds to the MineStatusType code list from the MIN4EU database.*

operating
operatingContinuously
operatingIntermittently
notOperating
closed
abandoned
careAndMaintenance
retention
historic
underDevelopment
construction
pendingApproval
feasibility