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PREDICTIVE ASSESSMENT OF RARE EARTH OCCURRENCES IN EUROPE USING THE DATABASE QUERYING METHOD

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Introduction

Rare earth elements (REE) are a group of 17 metallic chemical elements that have relatively similar chemical and physical properties. They comprise the 15 lanthanides, plus scandium (sometimes excluded) and yttrium. REE are used in a wide range of manufactured products, especially in green energy and digital technologies, and are considered as critical raw materials by the European Commission[1]. China has the most abundant resources and production of REE in the world, although significant resources, either known or inferred, exist in other countries. The goal of the present study is to assess REE occurrences in Europe, using a predictivity methodology developed by BRGM to evaluate the favorability of known mineralization to host a targeted commodity, the DataBase Querying (or DBQ) method[2]. Its purpose is not to evaluate the REE endowment of Europe, but to pinpoint mineral occurrences that may contain REE, in order to identify favorable areas and help guiding further exploration works.

Data sources and preparation

Data that was used for this work came from both the EURare IKMS (see presentation from Cassard et al. in this conference) and the ProMine Mineral Deposit (MD) database[2]. Datasets required by the DBQ method have to include a large number of occurrences or deposits, and to list their type and the presence/absence of a wide panel of commodities. The EURare IKMS dataset was extracted and completed to list all contained commodities (deduced from the mineralogy mostly) and to classify deposits in 17 distinct metallogenic families (16 from the ProMine project, plus placers, even though it is not a metallogenic type sensu stricto), in order to apply subsequent processing to coherent deposit populations. Additional information from publication[3,4,5,6] was also included. The resulting 'augmented' dataset contained 158 REE deposits, amongst which 104 were sufficiently documented (in terms of deposit type and contained commodities) to be processed with the DBQ method. The

ProMine Mineral Deposit database was also queried for all deposits belonging to the identified metallogenic families, with their type and contained commodities. This ProMine dataset was merged with the 104 IKMS deposits. After removal of duplicates, the final dataset contained 8326 occurrences and deposits, classified in 17 metallogenic families and described for their content in 52 commodities. 244 deposits out of the 8326 contain REE.

Predictive assessment

The DBQ method was developed within the ProMine project[2], to perform predictive assessment on datasets that are not big enough to provide reliable results with “usual” methods (e.g., Weight of Evidence), which is often the case when targeted commodities are “rare” elements and/or by-products. The first step of DBQ is to calculate, for each metallogenic family, an enrichment ratio (ER, or ratio of frequency of REE in the metallogenic family vs. frequency of REE in the whole dataset). ER>1 indicates a metallogenic family enriched in REE, while ER<1 indicates a depleted one. Enriched metallogenic families are (by order of decreasing ER) alkaline/peralkaline intrusions (ER=26.25), pegmatites (ER=7.36), IOCG (ER=2.59), placers (ER=2.57), igneous replacement deposits (ER=1.77), residual deposits (ER=1.20), sandstone- and shale-hosted deposits (ER=1.19) and igneous intermediate deposits (ER=1.11). These 8 families contain a total of 2074 occurrences or deposits, amongst which 193 contain REE.

For each enriched family, a frequency of occurrence in all deposits containing REE was calculated, per commodity (Table 1). This spectrum of commodity frequencies per metallogenic family constitutes the signatures that will be searched for. Note that the “igneous intermediate” and “IOCG” families (in red in Table 1) have only 4 and 5 deposits, respectively, containing REE, therefore their signatures have little statistical value and must be considered cautiously. All deposits in the dataset are compared to the characteristic signature of the metallogenic family they belong to and ranked according to their proximity (or similarity) to this signature, using the following formula:

$$\text{rank} = \sum_{\text{commodity \#1}}^{\text{commodity \#52}} \left(\frac{\text{commodity frequency} \times \text{binary presence value}}{100} \right)$$

where “binary presence value” is 1 if the ranked deposit contains the commodity, or 0 if not.

In order to compare ranks between different enriched metallogenic families, ranks were ponderated by the enrichments ratios ER. We have then calculated a ponderated rank for each of the 2074 occurrences belonging to the 8 enriched metallogenic families.

Results and Conclusion

The DBQ method is not spatial in its principle (i.e., the location of a mineralization has no impact on its rank). However, as we know the geographic coordinates of deposits, it is possible to spatialize the results, for instance by drawing maps of rank density. Figure 1 is a map of kernel density of ponderated ranks in Europe. It highlights areas of high density that are a priori favorable for REE. Note that the distribution of results also depends on the spatial heterogeneity of records in the ProMine database (e.g., higher density of occurrences in France that therefore appears more favorable, compared to other countries with less data).

As alkaline/peralkaline intrusions is by far the most enriched metallogenic family, the map closely mimics their spatial distribution in Europe, highlighting potentially favorable areas, such as the Svidnya-Seslavtsi region in Bulgaria, or the Laacher See intrusion in western Germany. In addition, it shows favorable areas related to other metallogenic families. Examples are for instances IOCG deposits in the northern Svecofennian belt (northern Sweden), placers in French Britany and Normandy, pegmatites in southern Austria or the Iberian massif (northern Portugal), or numerous bauxite occurrences in the Delfi region (Greece).

Although the DBQ method is not dedicated to discovering new deposits, it is appropriate to assess favorability for by-products commodities in known occurrences where they were not necessarily searched for. The present study confirms that although REE are not mined in the EU, potential resources exist from a wide range of metallogenic provinces and geodynamic settings[7]. It highlights mineral occurrences and areas in Europe that are favorable for REE, according to their DBQ ranking, and could therefore be interesting targets for future exploration works.

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Table 1: Frequencies (in percent) of occurrence of commodities in deposits containing REE, or characteristic signatures per enriched metallogenic family; in yellow, 10≤frequency<40; in orange, frequency≥40. * note that the "all metallogenic families" column includes deposits from families that are not enriched in REE (ER≤1).

	All metallogenic families	Alkaline & Peralkaline intrusions	Igneous Intermediate	Igneous Replacement	IOCG	Pegmatites	SandStone and Shale-Hosted	Residual deposits	Placers
Number of deposits	244*	40	4	20	5	74	11	18	21
REE	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Fe	32,79	47,50	25,00	95,00	100,00	10,81	18,18	66,67	14,29
U	23,36	35,00	25,00	10,00	40,00	18,92	81,82	0,00	4,76
Ta	21,72	35,00	0,00	0,00	0,00	44,59	0,00	0,00	0,00
Nb	20,08	50,00	50,00	0,00	0,00	29,73	0,00	0,00	9,52
Al	18,03	25,00	25,00	0,00	0,00	13,51	18,18	94,44	0,00
Zr	17,62	37,50	75,00	0,00	0,00	2,70	9,09	50,00	47,62
Be	17,21	10,00	0,00	0,00	0,00	41,89	0,00	0,00	4,76
Th	15,98	40,00	25,00	0,00	0,00	10,81	18,18	0,00	33,33
Ti	12,30	20,00	0,00	0,00	20,00	1,35	9,09	11,11	42,86
Cu	11,89	0,00	50,00	50,00	0,00	1,35	18,18	5,56	0,00
Fl	11,89	42,50	0,00	5,00	20,00	4,05	9,09	0,00	0,00
Phos	8,61	22,50	25,00	0,00	40,00	2,70	27,27	0,00	9,52
Mo	8,20	0,00	25,00	15,00	40,00	5,41	0,00	5,56	0,00
Au	6,56	0,00	0,00	10,00	0,00	0,00	18,18	5,56	0,00
Cr	5,74	2,50	0,00	0,00	0,00	0,00	0,00	55,56	0,00
Li	5,74	5,00	0,00	0,00	0,00	9,46	0,00	5,56	0,00
Sn	5,33	0,00	0,00	10,00	0,00	5,41	0,00	5,56	0,00
Zn	5,33	15,00	25,00	0,00	0,00	0,00	0,00	5,56	0,00
Pb	4,92	7,50	25,00	0,00	0,00	0,00	0,00	5,56	0,00
Ag	4,51	0,00	0,00	5,00	0,00	0,00	0,00	5,56	0,00
Ni	4,51	0,00	0,00	0,00	0,00	0,00	0,00	50,00	0,00
Mn	4,10	10,00	0,00	0,00	20,00	0,00	0,00	11,11	0,00
Ba	3,69	12,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Co	3,69	0,00	0,00	5,00	0,00	0,00	0,00	11,11	0,00
Mg	3,28	5,00	0,00	0,00	0,00	1,35	9,09	11,11	0,00
W	3,28	0,00	0,00	0,00	0,00	1,35	0,00	5,56	0,00
Sr	2,87	15,00	25,00	0,00	0,00	0,00	0,00	0,00	0,00
Bi	2,46	0,00	0,00	10,00	0,00	2,70	0,00	0,00	0,00
As	2,05	0,00	0,00	0,00	0,00	0,00	0,00	11,11	0,00
Sb	1,64	0,00	0,00	0,00	0,00	0,00	0,00	5,56	0,00
Cd	1,23	0,00	0,00	0,00	0,00	0,00	0,00	5,56	0,00
V	1,23	0,00	25,00	0,00	0,00	0,00	0,00	5,56	0,00
Rb	0,82	0,00	25,00	0,00	0,00	0,00	0,00	0,00	0,00
Se	0,82	0,00	0,00	0,00	0,00	0,00	0,00	5,56	0,00

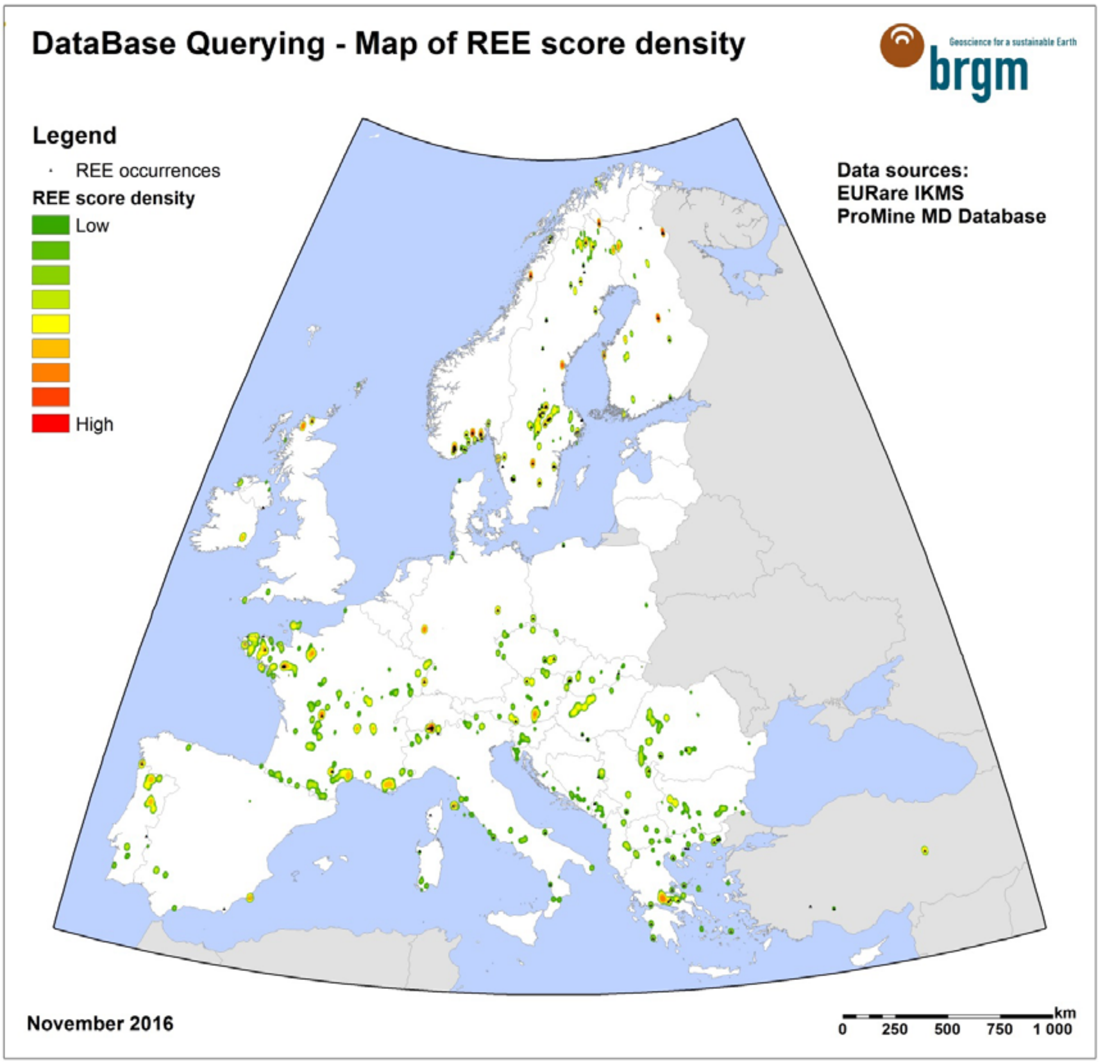

Figure 1: Map of kernel density of ponderated REE scores in Europe, obtained by the DBQ method.