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Database: Potential supercritical conditions

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Introduction & summary

Very high-temperature reservoirs are a possible target for future geothermal exploration either through the direct exploitation of super-critical fluids or as a potential high-temperature reservoir for Enhanced Geothermal Systems. By exploiting subsurface fluids at super-critical conditions, i.e. high temperature (>375 °C) and high pressure (>22 MPa), the energy output per well will increase by a factor of ~10. This will reduce development costs by decreasing the number of wells needed (IEA Technology Roadmap 2011).

In order to contribute to the EU strategic energy and climate targets for 2020 and 2050 by fostering increased growth in the geothermal energy market through enhanced awareness of the potential of geothermal energy production, a database of potential supercritical resources has been launched by the IMAGE project.

Superhot and supercritical resources are expected in the surrounding of still hot magmatic intrusions in the crust. A large part of the IMAGE activity focused on understanding what are the favorable conditions at a few km depth for shallow magmatic emplacement, beside improving exploration and investigation techniques for their detection and the related hot water circulation. In a typical crust with an average thermal gradient of the order of 30-35 °C/km the critical temperature of a brine (temperature above 450 °C) is reached at depth greater than 12-15 km. However, in many sites around the world (e.g. Larderello and Phlegraean Fields in Italy, Nesjavellir in Iceland, The Geysers in California) where exploratory boreholes were drilled in high-temperature geothermal system (T > 370 °C), reservoir pressures above supercritical conditions (>22.1 MPa) were encountered. These evidences confirm that geothermal reservoirs in supercritical conditions, both in temperature and pressure, exist in the vicinity of cooling magmatic intrusions. Volcanic rifts, extensional basins and/or subduction zones with related shallow crustal magma emplacements, are the more promising environments in which supercritical conditions may be found in the upper to middle crust levels,

The compilation of a European database of the favourable indicators of the presence of supercritical geothermal resources has been a main task in the IMAGE project. The objective is to define areas in Europe where supercritical fluids occur at a drillable depth with a manageable chemistry composition can be found. Where do we find fluids at 4-5 km depth with a temperature exceeding 400 °C? In various regions in Europe, including Iceland, Italy, Azores, Montserrat, Canary Island. What characterizes these areas? Can we find other areas with similar features at greater depth? We focus on Iceland, where these resources have been searched and studied in the last decade. We used the experience of research in Larderello, described in detail in other IMAGE deliverables (e.g. D5.01), to look for indicators applicable over broad areas, in search of potential supercritical resources in continental Europe. Since temperature is the key parameter controlling the presence of supercritical reservoirs at (relatively) shallow depth, mapping of supercritical resources was mainly driven by thermal models derived from crustal and lithospheric constraints and data interpolation from available deep wells. Other information providing indirect indication of crustal thinning and shallow magmatic emplacement have been searched and analyzed. In particular, we mapped the following indicators: the depth of 400 °C isotherm; the MOHO depth and crustal thickness; the earthquake density combined with the estimated depth of the Brittle-Ductile Transition in Europe. Other interesting indicators, e.g. He^3/He^4 ratio values from which fluids of crustal origin may be inferred, or Curie Point depth that refers to deep temperature regime, are available only for local areas, and are too restricted to be of use at regional and European scale. The location of recent (Pleistocene-Holocene) volcanism, also dispersed, was mapped since it provides useful information, but was not used in the computation of final maps. After defining the indicators, their spatial correlation was established by Geographic Information System (GIS) models, and a database was organized. By prioritizing favourable conditions using GIS spatial analysis methods, the “favourability” map of geothermal resources at supercritical condition was then obtained. It provides a clear overview of the distribution of potential resources in Europe, based on analytical data.

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1 Executive Summary

A technological breakthrough that has the potential to make deep geothermal exploitation very profitable, by expanding by several times the geothermal electric generation potential, regards the possibility to exploit deep geothermal fluids in supercritical conditions. This deliverable describes the parameters governing supercritical conditions and the places where they can be encountered and exploited in Europe. After describing the potential supercritical resources in Iceland that have been explored and studied in the last decade, and following the experience gained in Larderello, which has been described in detail in other IMAGE deliverables (e.g. D5.01), we looked for indicators applicable over broad areas, in search of potential supercritical resources in continental Europe. Since temperature is the key parameter controlling the presence of supercritical reservoirs at (relatively) shallow depth, mapping of supercritical resources was mainly driven by thermal models derived from crustal and lithospheric constraints and data interpolation from available deep wells. Other information providing indirect evidence of crustal thinning and shallow magmatic emplacement has been examined and analysed. In particular, we mapped the following indicators: the depth of 400 °C isotherm; the MOHO depth and crustal thickness; the earthquake density combined with the estimated depth of the Brittle-Ductile Transition in Europe. Other interesting indicators, e.g. He^3/He^4 ratio values from which fluids of crustal origin may be inferred, or Curie Point depth that refers to deep temperature regime, are available only for local areas and are too restricted to be of use at regional and European scale. The location of recent (Pleistocene-Holocene) volcanism, also dispersed, was mapped since it provides useful information, but was not used in the computation of final maps.
After defining the indicators, their spatial correlation was established by Geographic Information System (GIS) models, and a database was organized. By prioritizing favourable conditions using GIS spatial analysis methods, the “favourability” map of geothermal resources at supercritical condition was then obtained. It provides a clear overview of the distribution of potential resources in Europe, based on analytical data.
Besides mapping resources, we have made a step towards a more detailed and systematic resource reporting system in Europe related to supercritical geothermal resources.

2 Introduction

The exploitation of supercritical geothermal resources, i.e. subsurface fluids of extremely high temperature and pressure, may become a game changer in the power generation market. Above the critical point (374 °C, 22.1 MPa for pure water) the physical properties of a fluid changes. In particular, the changes in buoyancy/density characteristics, as well as fluid viscosity, are so extreme that high rates of energy and mass transfer can be harnessed. In a typical crust with an average thermal gradient of the order of 30-35 °C/km, the critical temperature of a brine (T above 450 °C) is reached at depths greater than 12.5-14.5 km. As described in Reinsch et al., 2017, temperatures in excess of 374 °C have been found at depth in a few tens of wells around the world (The Geysers, Salton Sea, and Hawaii in USA, Kakkonda in Japan, Larderello and and Phlegraean Fields in Italy, Krafla in Iceland, Los Humeros in Mexico, and Menengai in Kenya). These super-hot resources, essentially found at the roots of very high temperature hydrothermal systems associated with volcanic areas and shallow magma emplacement, not always correspond to super-critical pressure values. The latter require either large depths or the presence of a sealing horizon allowing the pressure to exceed vaporstatic/hydrostatic conditions.
Only recently the technological development allowed serious consideration of exploiting supercritical conditions. The extreme temperature and pressure conditions, as well as the presence of a very aggressive fluid composition, require innovative technologies and research breakthroughs in a number of fields, including exploration, drilling, well completion and fluid handling.
At the moment, fluids at supercritical condition have been reached in Iceland (IDDP-2 project and the related DEEPEGS project), and investigation of supercritical systems is underway in Larderello (Italy, where the DESCRAMBLE project is presently in the drilling phase), Japan (northern Honshu),
Iceland (Reykjanes peninsula and Krafla), Mexico (Los Humeros), USA (Newberry), and New Zealand (Taupo Volcanic Zone).

This report provides a practical analytical framework for the systematic capture of information relevant to the assessment of supercritical geothermal resources in Europe. We are not dealing with the issues related to the access and management of supercritical fluids, which is the focus of other running projects. The approach described here is aimed at establishing indicators for the presence of supercritical geothermal conditions at depth, at organizing and integrating data, and by providing a methodology to establish a hierarchy of European areas based on their potential for hosting supercritical resources at accessible depth. We used Geographical Information System

(GIS) software tools for the spatial analysis of multiple parameters to assist selection of prospective sites, based on pre-defined criteria which we discuss in Chapters 4 and 5.
We use here the terminology of “favourability” maps, previously adopted by similar studies (e.g., Prol-Ledesma, 2000; Coolbaugh et al., 2002; Noorollahi et al., 2007; Yousefi et al., 2010; Tufekci et al., 2010; Trumpy et al., 2015).

In this report we first focus on Iceland, where supercritical resources have been searched, studied in detail and reached thanks to IDDP projects. We then describe our approach for a supercritical resource database in Europe, we discuss the information used for our analysis and we provide the results, i.e. the favourability map of supercritical resources in Europe. The map includes only areas where harmonized data maps were available.

3 Supercritical system potential in Iceland

The objective of mapping possible geothermal sites with potential supercritical conditions in a volcanic environment comes down to finding supercritical fluid at a drillable depth: where do we find 400 °C fluid at 4-5 km depth? These sites are found in volcanic zones, e.g. Iceland, or in areas with shallow magmatic emplacement, e.g. Italy.
The estimated potential geothermal power in Iceland is based on volumetric assessment from Pálmason et al. (1985) and has not been updated since. Geothermal power of some 3,500 MWe are assumed from known geothermal fields within the upper 3 km. This figure should be reduced to at least 50% due to environmental and economic constraints. Technically accessible geothermal potential outside these known high temperature fields is estimated to be around 40,000 MWe. This figure could increase significantly when taking into account the recent evolution of Enhanced Geothermal Systems (EGS) and utilization of Supercritical Geothermal systems (SGS) at depths greater than 3 km as well as submarine geothermal fields where high temperature are expected at shallow depths below the bottom of the sea.
In the past decades, drilling technology has developed immensely making it technically feasible not only to drill down to a depth of 3 km but to a depth of 6 km or even more. According to Fridleifsson et al. (2005), the energy output per volume unit from wells with supercritical fluid can be as much as 5-10 times higher than conventional high temperature fluids. These systems are called Supercritical Geothermal systems (SGS).
Supercritical conditions for pure water are reached at temperatures higher than 374 °C and at a pressure of about 22.1 MPa. For saline fluids these values are slightly higher. In Reykjanes, SW-Iceland, the reservoir fluids have the salinity of seawater resulting in a critical point at 406 °C at 29.8 MPa (Fridleifsson and Elders, 2017).
The background temperature gradient in Iceland is 40-140 °C/km (Flóvenz and Sæmundsson, 1993 – see Figure 1), temperatures up to 340 °C are found at a depth of 2 km in several high temperature systems in Iceland. Conservative estimates indicate that temperatures above 400 °C are found at a depths of 4-5 km within the volcanic rift zone. The pressure at those depths should be adequate to create supercritical conditions assuming hydrostatistical pressure. Additionally, the extensional stress field in combination with the large frequency of earthquakes suggest the presence of considerable permeability in the recent fracture system. Interpretation of earthquake and temperature data, indicate that the brittle-ductile boundary in the basaltic crust of Iceland is an isothermal surface in the range 600-800 °C (Ágústsson and Flóvenz, 2005). Laboratory measurements on cores at high strain rate give similar results but considerable lower values (550 +/- 100 °C) when extrapolated to geological strain rates (Violay et al., 2012). These are presumably the lower boundary of exploitable geothermal energy and could be related to the deep laying conductive bodies delineated by magnetotelluric (MT) resistivity data at depths of 5-10 km in the volcanic zone.
The landward continuation of the oceanic spreading ridge crosses Iceland from south-west to the north-east (see Figure 1). The rift zone (younger than 0.8 Ma) forms a belt of volcanism and rifts, composed of many active central volcanoes emplaced in a fissure swarm where spreading occurs. The uppermost 1 km of the zone is composed of permeable young basaltic material. Within the central volcanoes or their fissure swarms some 30 on-land high temperature geothermal fields are

found (temperature higher than 200 °C at a depth of 1 km). The active volcanic zones of Iceland cover an area of 32,000 km^2. Around 2,000 km^2 form the active part of these zones.
The supercritical potential in Iceland is, therefore, restricted to the 32,000 km^2 active volcanic zone where fluids at supercritical conditions are expected at drillable depths of 4-5 km.

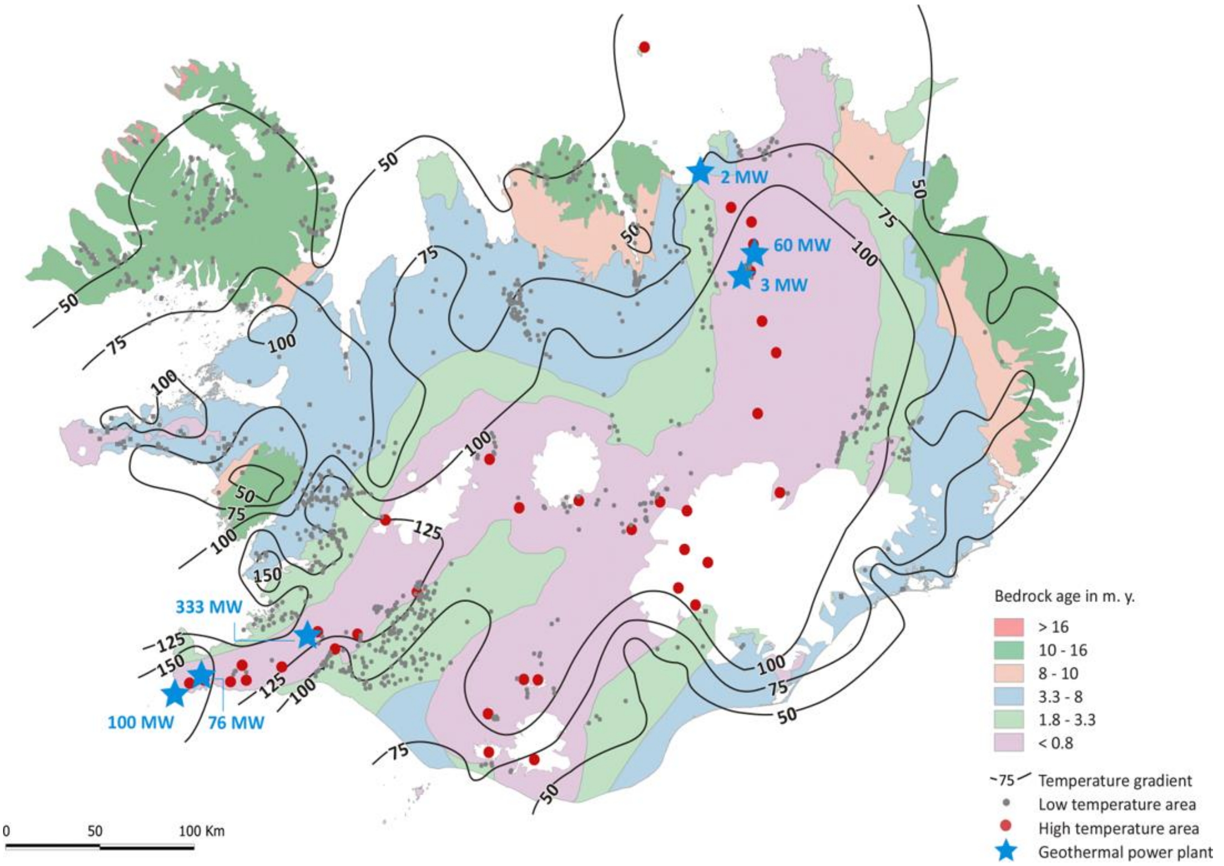

Figure 1. Geothermal map of Iceland, showing the known geothermal fields, the electricity production in geothermal power plants, isolines of temperature gradient and age of the bedrock. The data are derived from ISOR's database. Rocks younger than 0.8 Ma corresponds roughly to the present volcanic rift zones (from Flóvenz and Steingrímsson, 2009).

4 Parameters characterizing potentially exploitable supercritical systems

The most important preliminary activity for the favourability assessment is the identification of the favourable (or prospective) parameters for the origin and storage of supercritical resources. In this context, the concept of the geothermal play (Moeck, 2014; Santilano et al. 2015 and reference therein) is of great importance. A geothermal play can be considered as a conceptual model, in the mind of a geologist, of a number of geological factors that combine to produce the resource in a specific stratigraphic level. A detailed and critical review of the supercritical systems, also on our understanding of the deep, possibly supercritical conditions of the Larderello system in Italy (see IMAGE Deliverable D5.01), allowed us to define the main parameters to be considered in our semi-quantitative assessment of the favourability of these systems. After defining the useful indicators, we focused on those applicable to broad areas, in order to perform a harmonized analysis on the European territories (mainland). For our purpose, thematic information in the form of maps (layers) were organized in a GIS database model, and combined to assist in the selection of prospective geothermal sites.

The major and direct source of data is the thermal model of Europe. Temperature, coupled with pressure, is indeed the major control to the supercritical state of fluids. We used the crustal thermal model based on Limberger et al., 2016 (see IMAGE Deliverable D6.01). To take the thermal regime into account and highlight anomalously hot areas, we computed the depth of a reference isotherm, following an already established practice (Trumpy et al., 2015). The choice of the reference temperature is related to the exploitation technology; e.g. in Trumpy et al. (2015) the reference temperature for the favourability of hydrothermal resources to be used for power generation is 120 °C. As already mentioned, the supercritical point of pure water is 374 °C with a pressure of 22.1 MPa, while saline water requires a higher temperature. In this study, we used the depth of the 400 °C isotherm as reference. This temperature, roughly corresponding to supercritical temperature of a seawater pore fluid, is probably lower than that of geothermal deep fluids (brines), which are expected to have much higher salinity. However, these fluids have not yet been sampled and any temperature at the moment is just a speculation. Our choice for a temperature (400 °C) should not be taken as an absolute reference: we are just interested in the isotherm's depth distribution, which would be essentially the same for isotherms of similar value (374-450 °C) (Figure 2).

Another important source of data that is of interest for the computation of the favourability is the depth of the MOHO discontinuity, considering the relationship between thinned crust (and therefore shallower MOHO depth) and anomalous thermal regimes. This depth was computed from the model of Tesauro et al., 2008 (Figure 3). Larderello is a major example of high temperature system located in an area of crustal thinning.

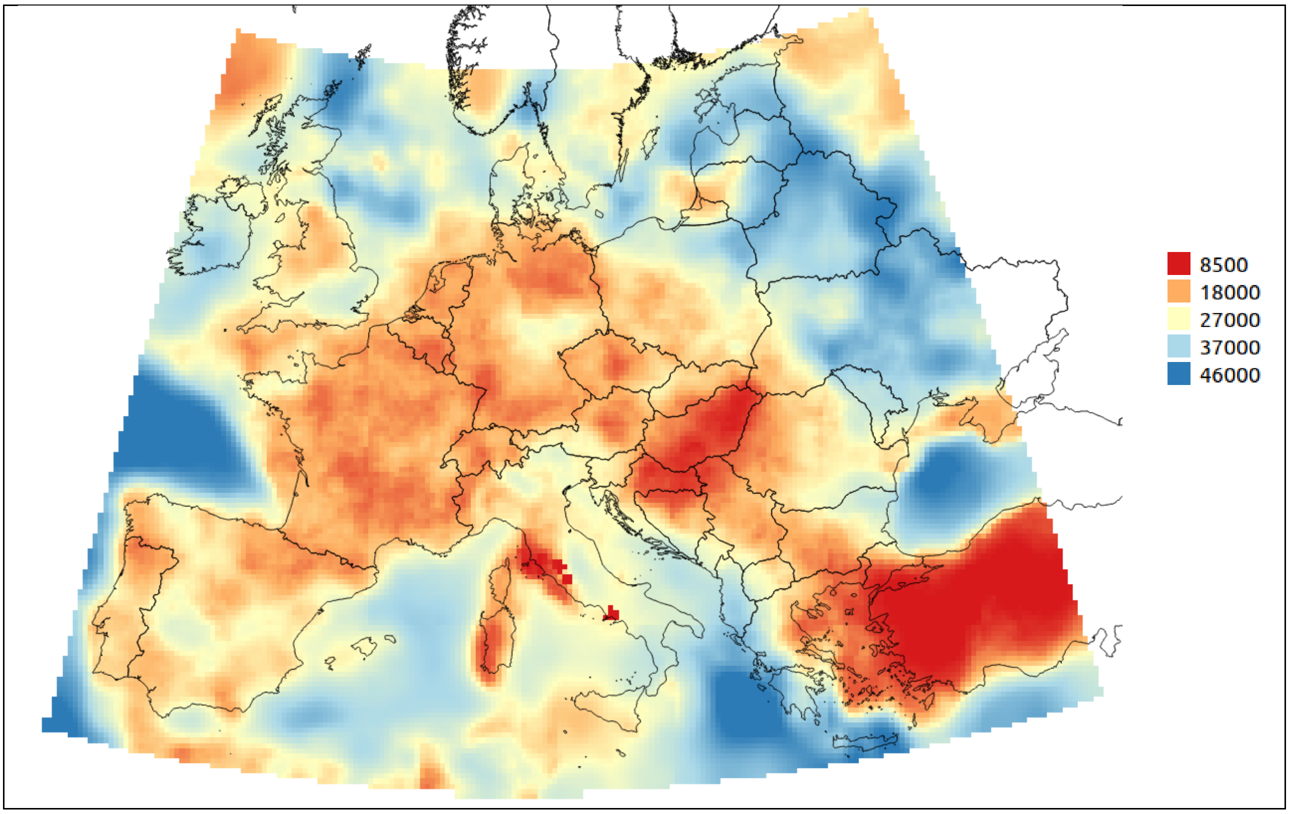

Figure 2. Distribution of the depth of 400 °C isotherm calculated from the thermal model. In the legend, depth in m b.g.l.

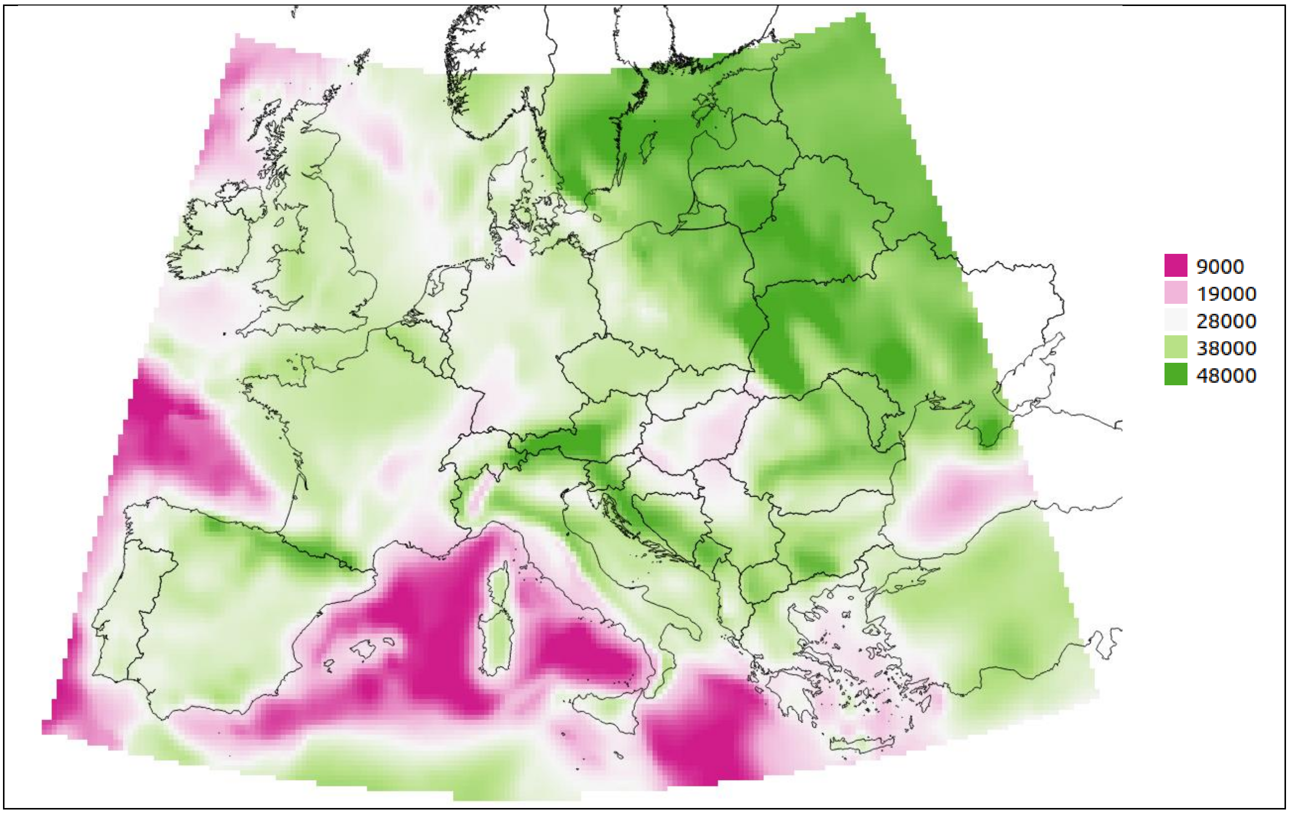

Figure 3. Distribution of MOHO thickness (after Tesauro et al., 2008). In the legend, thickness in m.

The experience gained worldwide indicates that the occurrence of buried igneous intrusions is essential for the development of a thermal regime suitable for the emergence of supercritical conditions. In addition to the very high temperature conditions, the thermo-metamorphic aureole itself and the occurrence of metasomatic fluids can represent a target for supercritical geothermal projects.

The prospective index of recent (< 1Ma) volcanic or deep buried magmatic activity must be considered. A first indication is provided by geological maps to check the occurrence of recent volcanic activity (as expression of deep magmatic chambers). For this reason, we mapped the Pleistocene-Holocene volcanic centres from the database “Volcanoes of the World” (http://volcano.si.edu/). This catalogue, which organize volcanoes active during the Pleistocene period (approximately the last 2.5 Ma) and with eruptions during the Holocene period (approximately the last 10 ka) or at present time, currently contains 157 volcanoes within the European countries and surrounding seas. The volcanic centres appear quite scattered in the continental Europe and exhibit a cluster of magmatic centres around the Mediterranean regions (Fig. 4).

This information layer is not exhaustive as the igneous intrusions not always produce volcanic activity. This is the case for the Tuscan magmatic province, hosting high temperature hydrothermal systems, where a number of cooling or still molten intrusion is supposed to be emplaced at very shallow depth without any extrusive activity. Since the reported centres have a local meaning and cannot be extrapolated over distance, this information remains extremely sparse. Hence, we use this map as a reference but the related information is not directly used in the final computation of favourability.

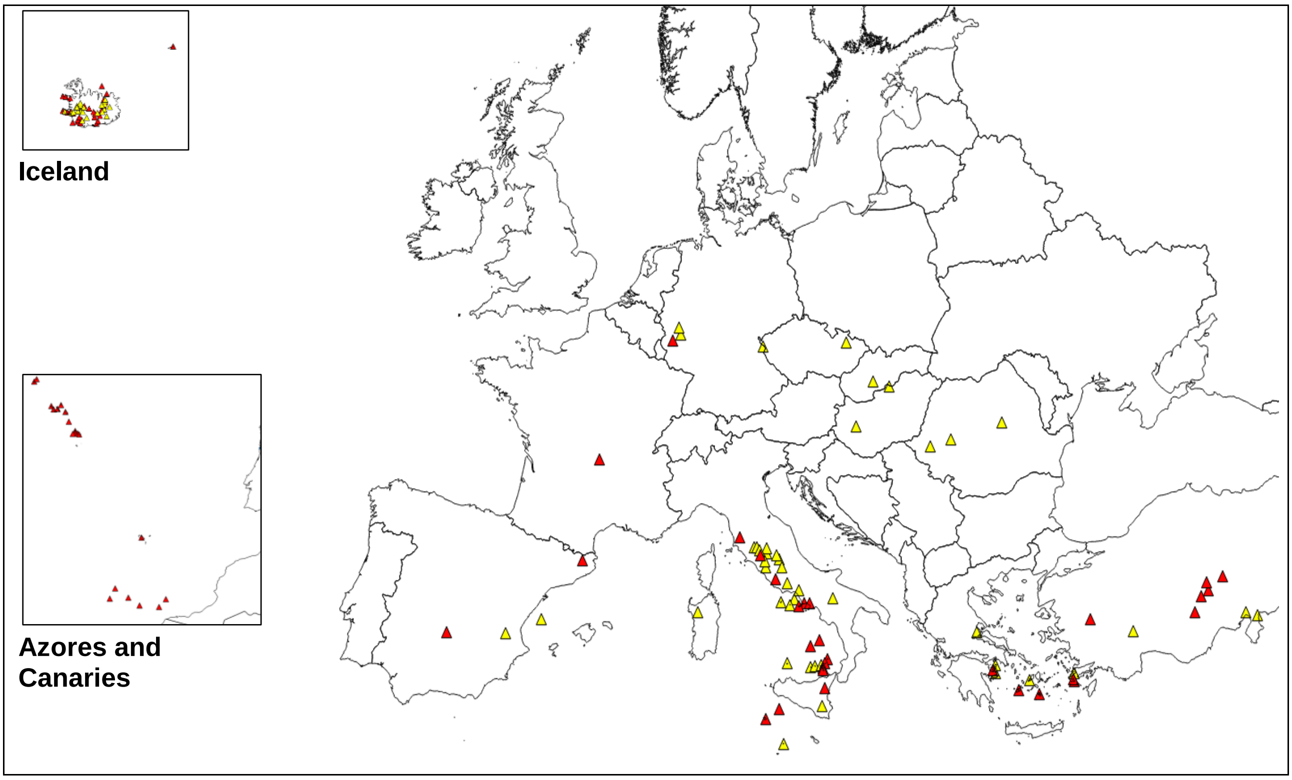

Figure 4. Pliocene-Holocene volcanic centres. Yellow triangles: Pleistocene volcanoes.

Geophysical parameters can provide important information on the occurrence, depth and extension of buried molten intrusions. E.g., in the frame of the IMAGE deliverable (D5.1), an integrated study of magnetotelluric, gravimetric and seismological data allowed the characterization of the heat (and possibly metasomatic fluid) source of the system, i.e., the granitic, locally partially molten intrusion, while a bright-spot seismic marker hints for highly permeable levels rich of supercritical fluids. This approach, based on field-scale exploration data, is not applicable to European scale studies. We explored the possibility to use gravimetric data, in particular local and relative minima of the Bouguer anomaly, as index of low density anomalies at depth due fractional melting. Such an approach would have required an extensive modelling of the European crust to filter out other causes of low density, which required an effort beyond the scope of IMAGE Task 5.5. This set of geophysical data could therefore not be used. Also the Curie Point depth, retrieved from Earth Magnetic field, was considered an important piece of information, since it provides independent geophysical evidence of the depth distribution of the temperature at which magnetic minerals demagnetize. Curie Point maps provide important information on the occurrence of partial melts at shallow depth. Unfortunately, the lack of European coverage led us to discard this data.

The option that we explored was a combined analysis of two sources of data available at European scale: the depth of the brittle-ductile transition (BDT) in the strike-slip regime and the seismicity. The concept here explored is that the movement of magma and the related hydrothermal circulation is associated with a certain amount of seismicity, usually with high frequency and low magnitude. On the other hand, very shallow depth of the BDT may indicate the presence of igneous intrusion. A combination of frequent seismicity and shallow BDT provides a good indication of geodynamic conditions favourable to shallow magmatic emplacement.

The hypocentre location map of the Earthquake Catalogue (from the SHARE project http://www.share-eu.org) was then used for computing the earthquake density in each cell of 20x20 km^2 size, and a quadratic kernel function smoothing on the earthquake densities was applied (Fig. 5). The BDT was computed from the European strength model (Limberger et al., 2016, see IMAGE

Deliverable D6.01) considering a constant strain-rate comparable to background intraplate deformation rates (we used 10^{-15}). (Fig. 6) Although a magmatic emplacement strain rate could be as high as 10^{-12}, these high values would be very localized and we neglected this effect. Moreover, in most cases these areas are also highlighted in the map of recent activity volcanic centers. Since BTD depth depend also on the tectonic regime and in order to harmonize the different tectonic regimes at European scale, considering that the bulk of the continent is in a tectonic stable condition, the BDT depth was computed assuming a strike-slip regime. After computing the BDT depth, the earthquake density was filtered: only events located where the BDT results shallower than 9.5 km were considered (Fig. 7).

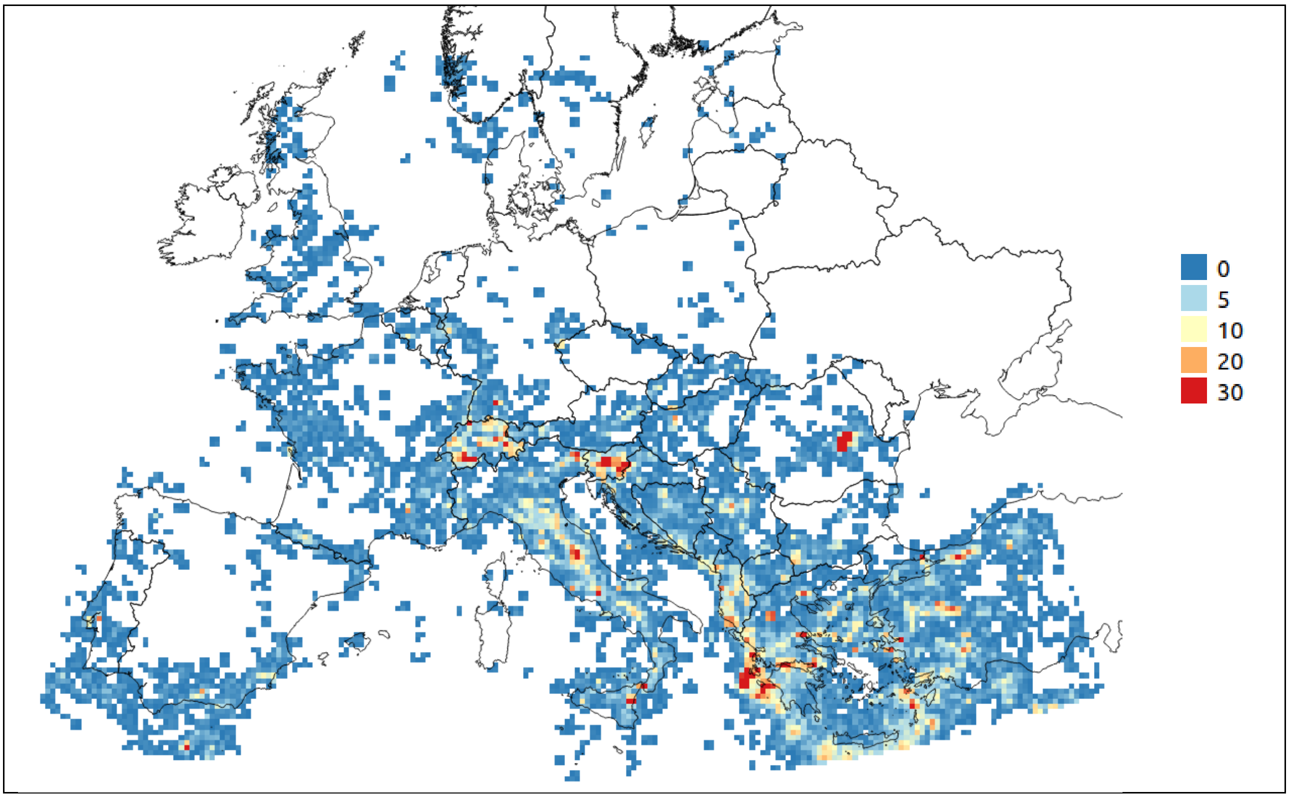

Figure 5. Earthquake density (from Earthquake Catalogue). In the legend, number of earthquake per cell (20x20 km^2).

Finally, the role of geochemistry should be mentioned in the assessment of supercritical systems. E.g., the ^{3}He/^{4}He isotopic ratio of gas discharges is an important indicator of the presence of mantle magmas residing in the crust. Looking at the available geochemical data we concluded that also this dataset has not a global distribution at European scale, and we could not take it into account in our computation.

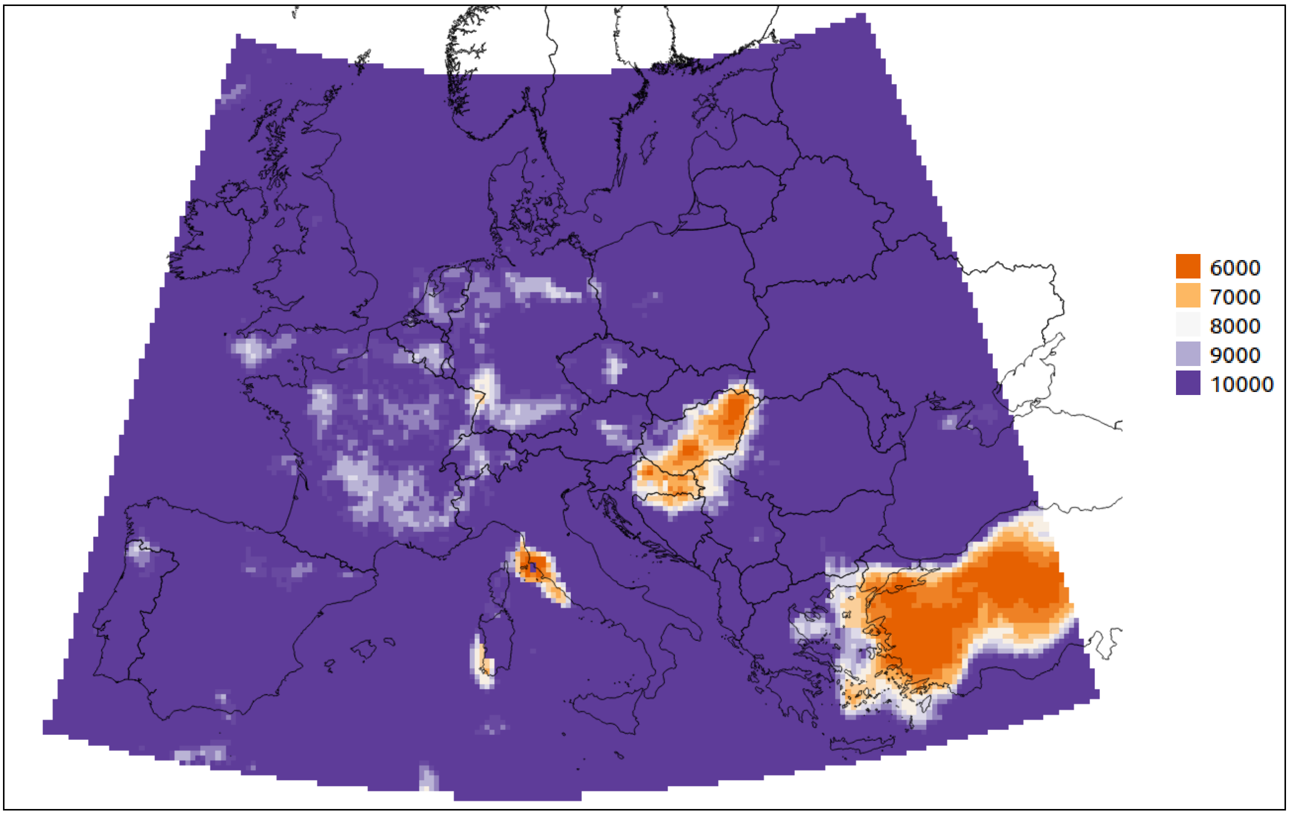

Figure 6. Depth of Brittle-Ductile Transition in Europe. See text for details. In the legend, depth b.g.l. in m.

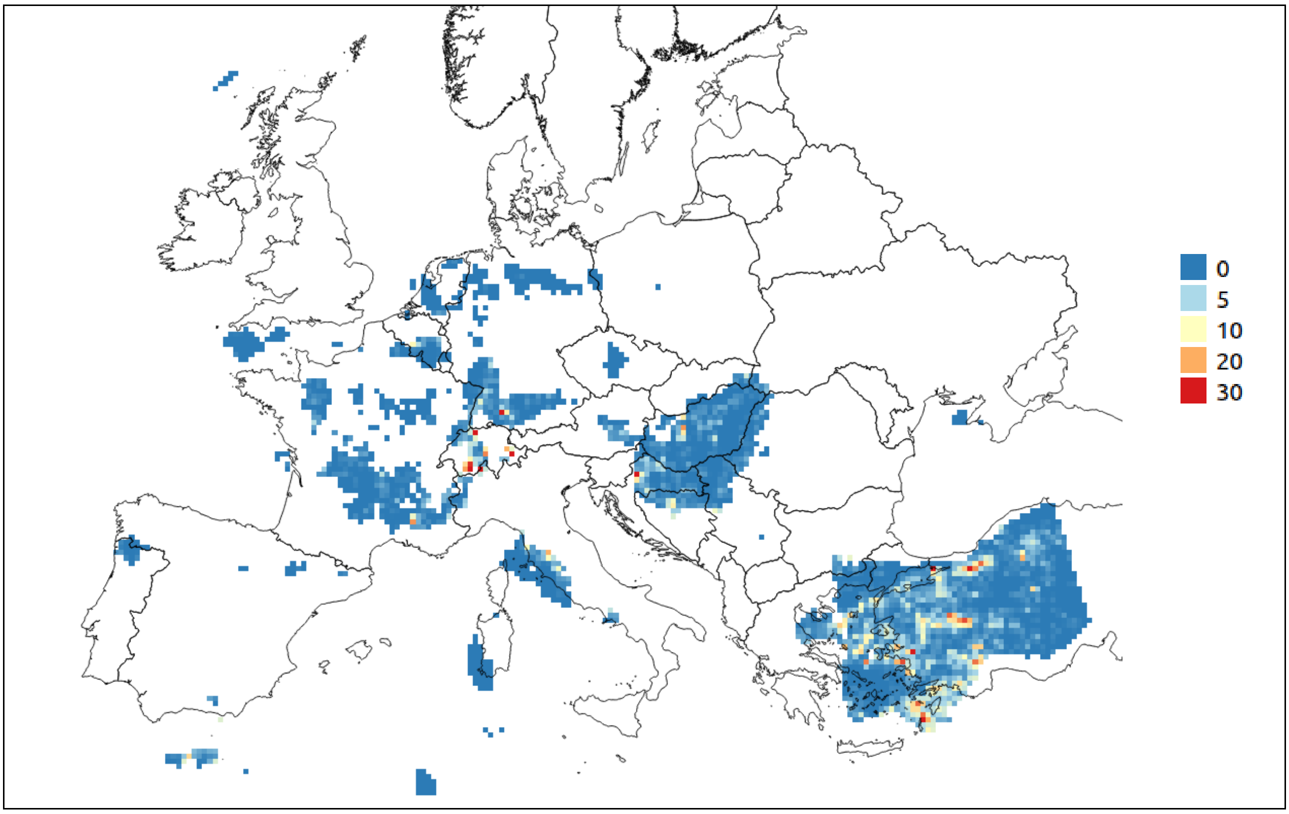

Figure 7. Earthquake density (from Earthquake Catalogue) for events located where the BDT depth is shallower than 9.5 km. In the legend, number of earthquake per cell (20x20 km^2).

5 Database description: data collection and organization

To produce favourability maps for supercritical geothermal resources in Europe, we used a GIS model to combine the geological and geophysical evidence previously described. In applying GIS tools, the conceptual model plays an important role in the choice of layers that will be involved in making a favourability map, as well as for scoring and weighting the selected layers. In our study, the score and weight in each layer have been estimated on the basis of expert opinion, following a “knowledge-driven” model and using the Index Overlay (IO) method. IO provides a flexible way to apply a common scale of values to non-uniform inputs, thus creating an integrated analysis. When information is organized in thematic maps (e.g., raster layers) with diverse value scales and importance, the values can be classified and scored before being overlaid. In addition, each information layer receives a defined weight.

The average score of the resulting map is therefore:

$$\overline{S} = \frac{\sum_{i=1}^{n} S_{ij}}{\sum_{i=1}^{n} W_i}$$

where S is the weighted score for each pixel, W_i is the weight for the i^{th} thematic map, and S_{ij} is the score for the j^{th} class of the i^{th} thematic map (Bonham-Carter, 1994).

We used the raster calculator to perform a favourability analysis and to develop an integration model making use of the spatial analysis capabilities of the open source software Quantum GIS and GRASS GIS. These tools overlay raster elements using a common spatial resolution, a common origin for the coordinates, and the same number of cells.

Before combining them, the three maps described in Chapter 4 were classified, scored and weighted. The classifications for each map consisted of identifying five ranges of values (classes). The classes were scored from 1 to 5, “Very low” (least favourable area) to “Very high“ (most promising area) respectively. Each map was then weighted with a value ranging from 0 to 1 (Table 1). The classified maps are shown in Figures 8, 9 and 10.

Thematic map	Weight	Score				
		5 (Very high)	4 (High)	3 (Medium)	2 (Low)	1 (Very low)
Depth of 400 °C isotherm	0.5	0-3500 m	3500-5000 m	5000-10000 m	10000-15000 m	15000-53037 m
Depth of MOHO	0.2	0-10000 m	10000-25000 m	25000-35000 m	35000-40000 m	40000-58491 m
Filtered earthquake density	0.3	30-112	10-30	5-10	0.9-5	0-0.9

Table 1. Scores of classes and weights for thematic maps used in the favourability analysis.

The three thematic maps were eventually combined by IO computation to produce the final map. Fig. 11 shows the computed favourability and the recent volcanic centres of Fig. 4.

Thematic map	Score				
	5 (Very high)	4 (High)	3 (Medium)	2 (Low)	1 (Very low)
Favourability map of supercritical resources in Europe	4.2-5	3.4-4.2	2.6-3.4	1.8-2.6	0-1.8

Table 2. Scores of classes for the Favourability map of supercritical resources in Europe

All maps, including raw data, constituting the database of supercritical resources of Europe, have been produced in grid (geotiff and asc) format for further analysis. The database will be made accessible through the IMAGE website.

The cartographic layout of favourability maps is provided in Annex 1.

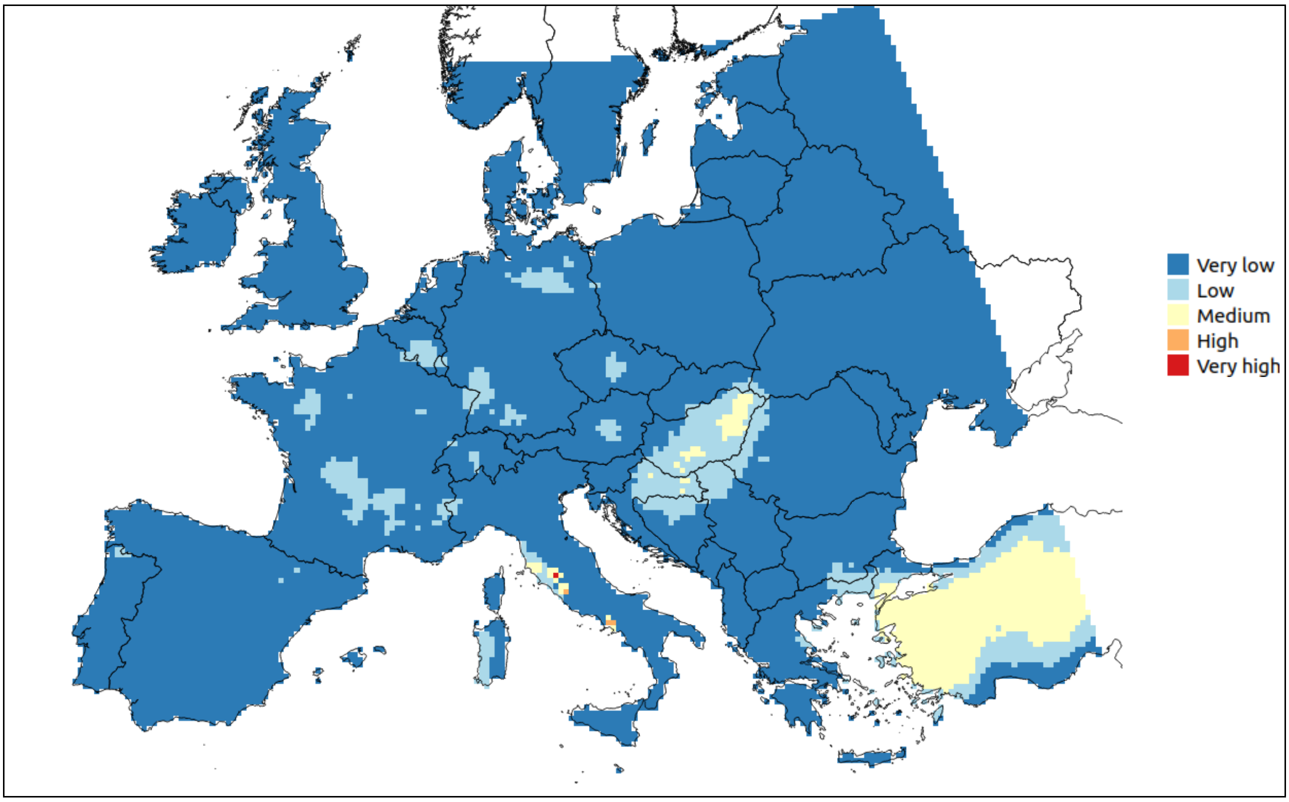

Figure 8. Reclassified map of the 400 °C isobath.

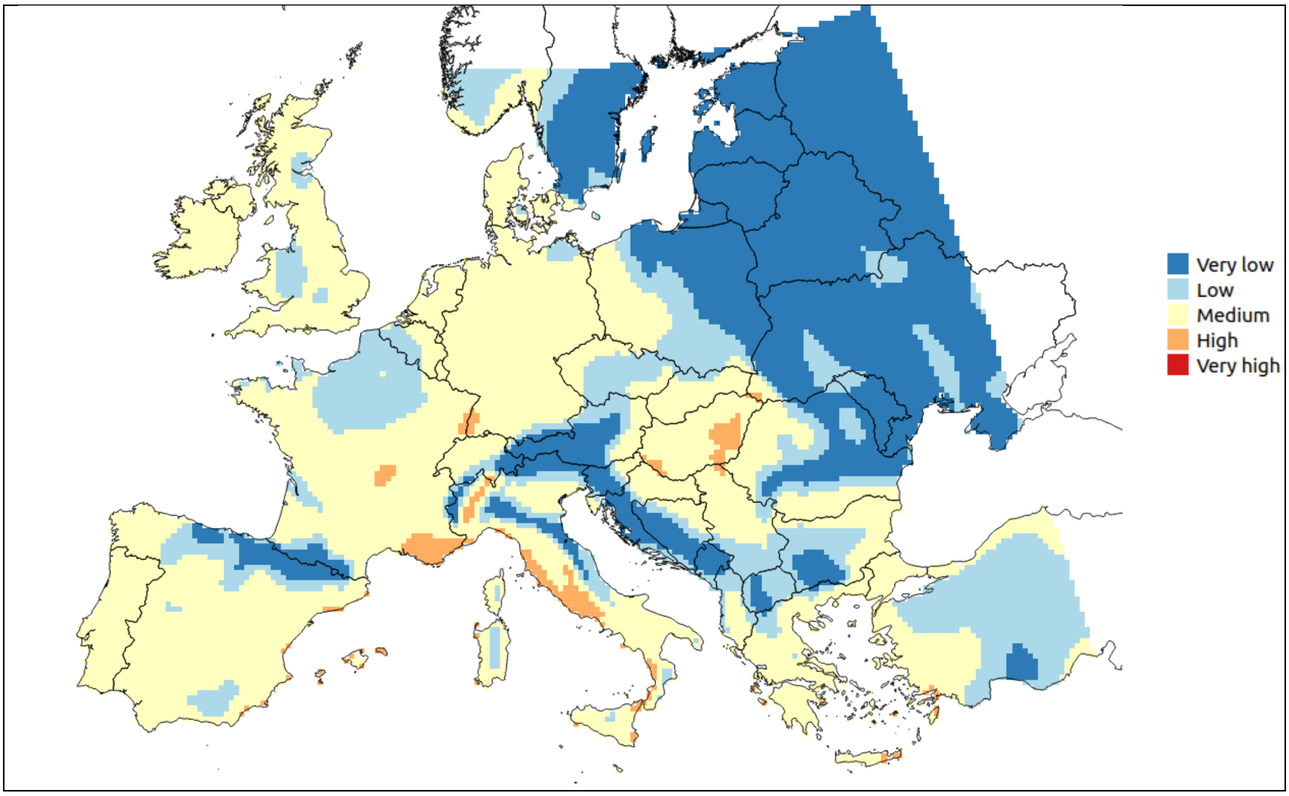

Figure 9. Reclassified map of the MOHO depth.

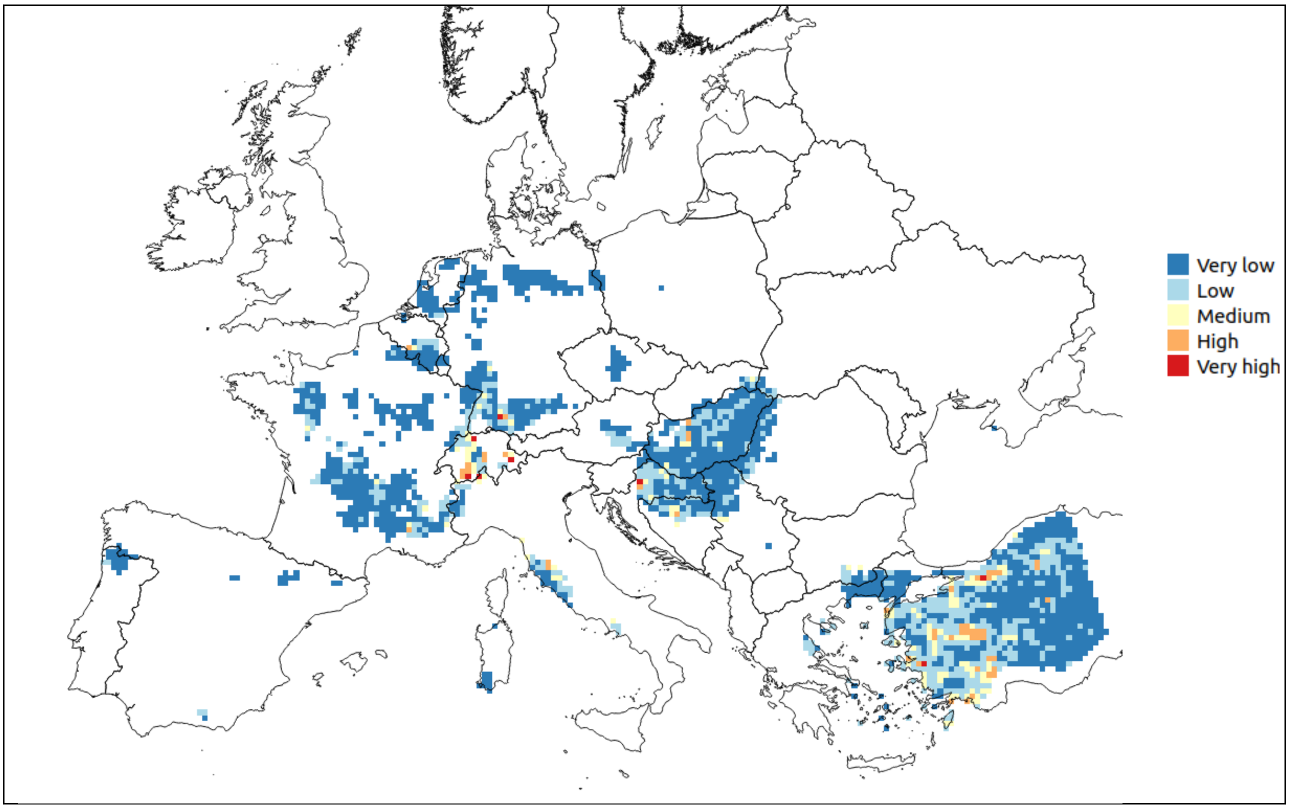

Figure 10. Reclassified map of the earthquake density for events located where BDT is shallower than 9.5 km.

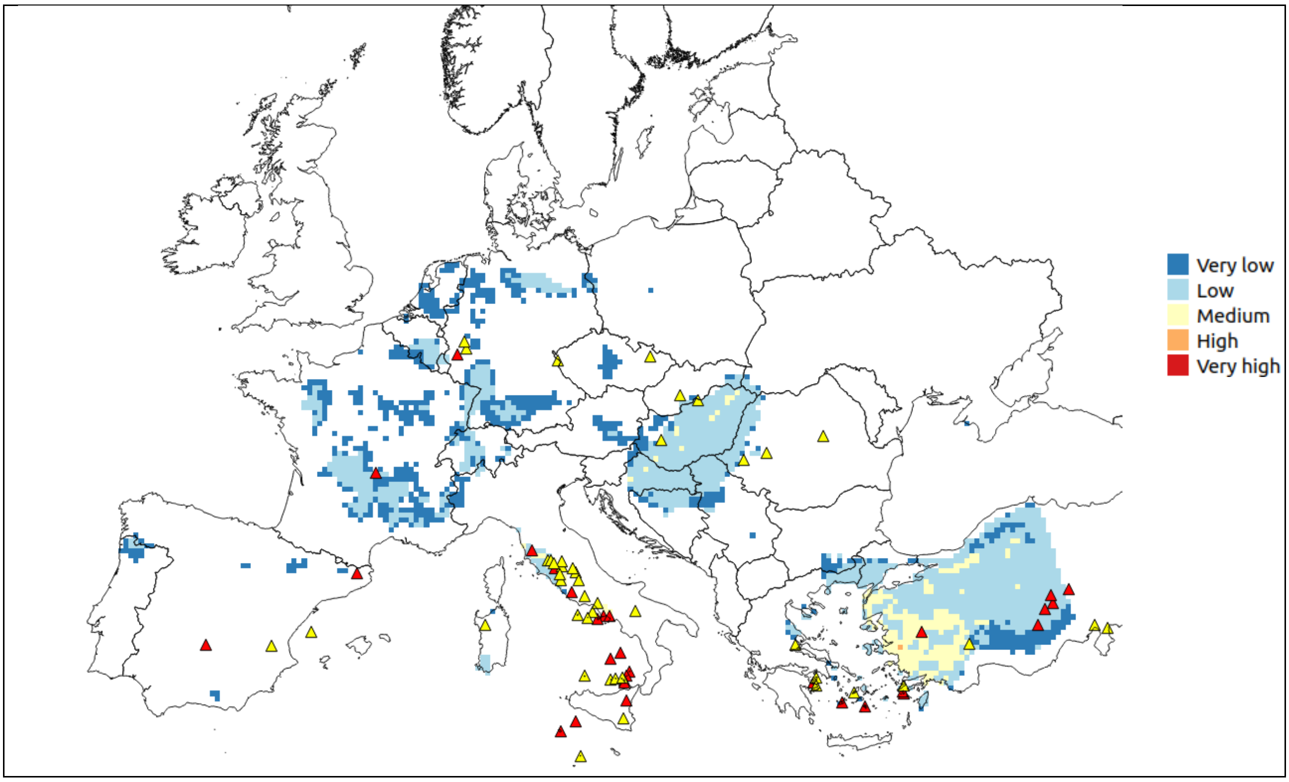

Figure 11. Map of favourability to host supercritical resources. In the legend, favourability ranking. Red triangles: Holocene volcanoes. Yellow triangles: Pleistocene volcanoes.

6 Supercritical system potential around Europe

The map in Fig. 11 shows the areas of Europe where geological conditions are likely to host supercritical resources at drillable depth, and are thus suitable for a more detailed exploration. Most European areas are not classified, since the data provide no evidence of supercritical condition at suitable depths. Large areas are, however, identified as potential place for supercritical resources. Low favourability values (in blue), are located mainly where the 400 °C isotherm is shallower or earthquake density particularly high. They are located in Turkey, Greece, Italy, the Pannonian Basin, and partially in Germany (Rhine Graben in particular), France. Some small areas in Switzerland, Belgium, Portugal and Spain are also included. The map highlights medium and highly favourable areas in small areas in Italy and Pannonian Basin, and large areas in Turkey. Recent volcanic areas, highlighted with triangles, are also preferential sites.

7 Conclusions

The favourability map of supercritical resources in Europe have been produced, and a database of favourable indicators built. The approach here described exploits modern geostatistical and GIS techniques and integrates indirect information related to supercritical condition at depth. The reliability of the favourability map relates to the availability and accuracy of data.
The favourability map highlights areas where investment in knowledge has the highest probability of being productive. The main aim of this map is to foster the growth of the geothermal energy market through enhanced awareness of the distribution and extension of potential supercritical resources. The corresponding potential for geothermal energy production could not be calculated, since at the moment there is no defined methodology for such an estimation.
The map has various limitations. First of all, it lacks any indication regarding pressure or permeability condition at depth. This analysis is, in our view, only possible at local scale. Secondly, the lack of detailed, updated and harmonized data at European scale, such as those related to Curie Point depth and crustal density models, largely reduce the number of indicators to be used. Thirdly, we still lack a complete understanding of supercritical resources and the behaviour and role played by the brittle-ductile transition. When these latter will be ruled out, possibly thanks to the present research projects DESCRAMBLE and DEEPEGS, it will be possible to add further constraints and information. Our tool is highly flexible: with a simple reclassification and computation it can incorporate other thematic maps and different ranking.

Besides mapping resources, we have made a step towards a more detailed and systematic resource reporting system in Europe related to supercritical geothermal resources. A reporting method is the basis for the portfolio management of geothermal resources and the selection of specific locations for geothermal power production projects.

8 References

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9 Annex: supercritical geothermal system database and favourability maps

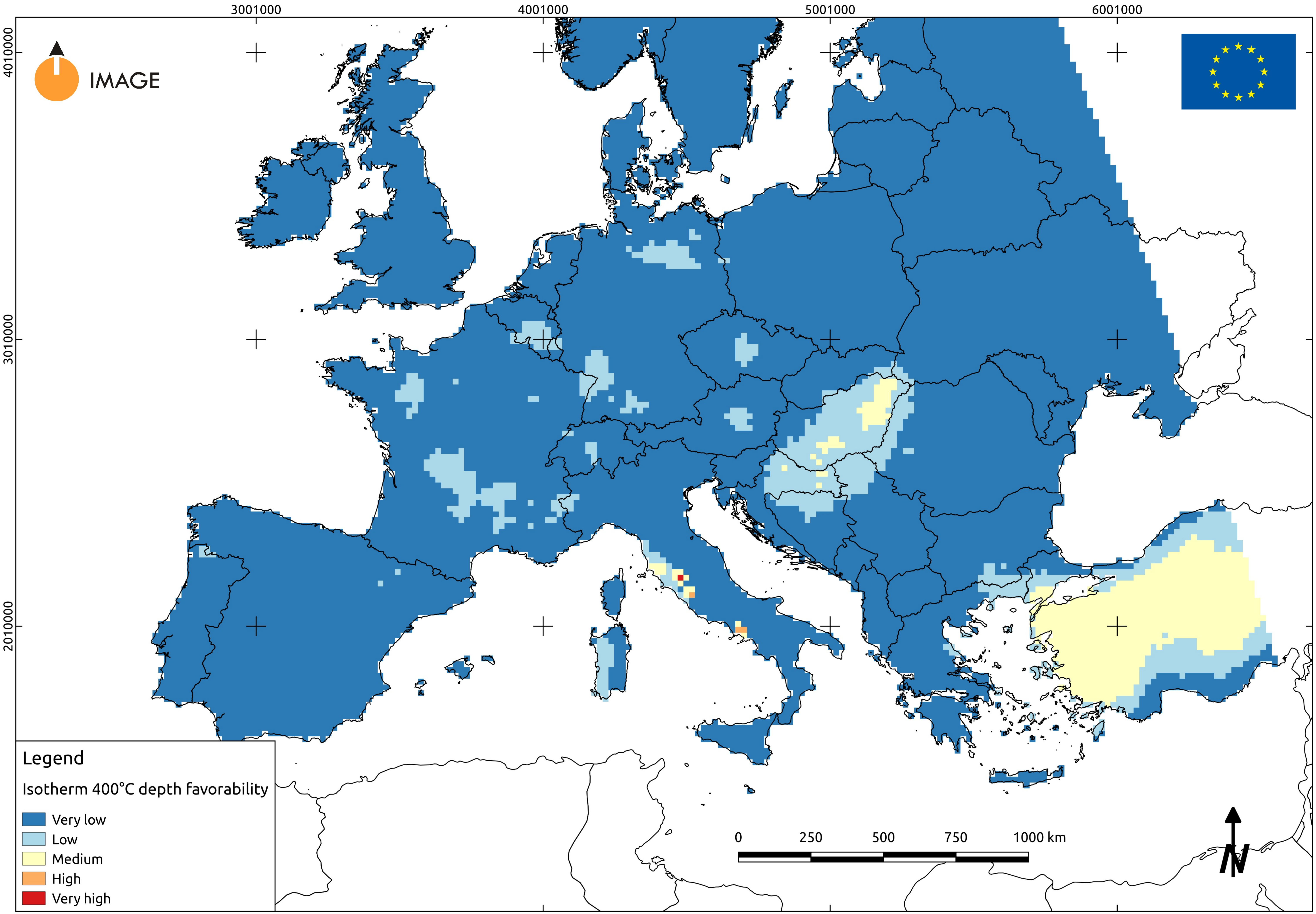
3001000
4001000
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IMAGE
Legend
Isotherm 400°C depth favorability
Very low
Low
Medium
High
Very high
0
250
500
750
1000 km
N

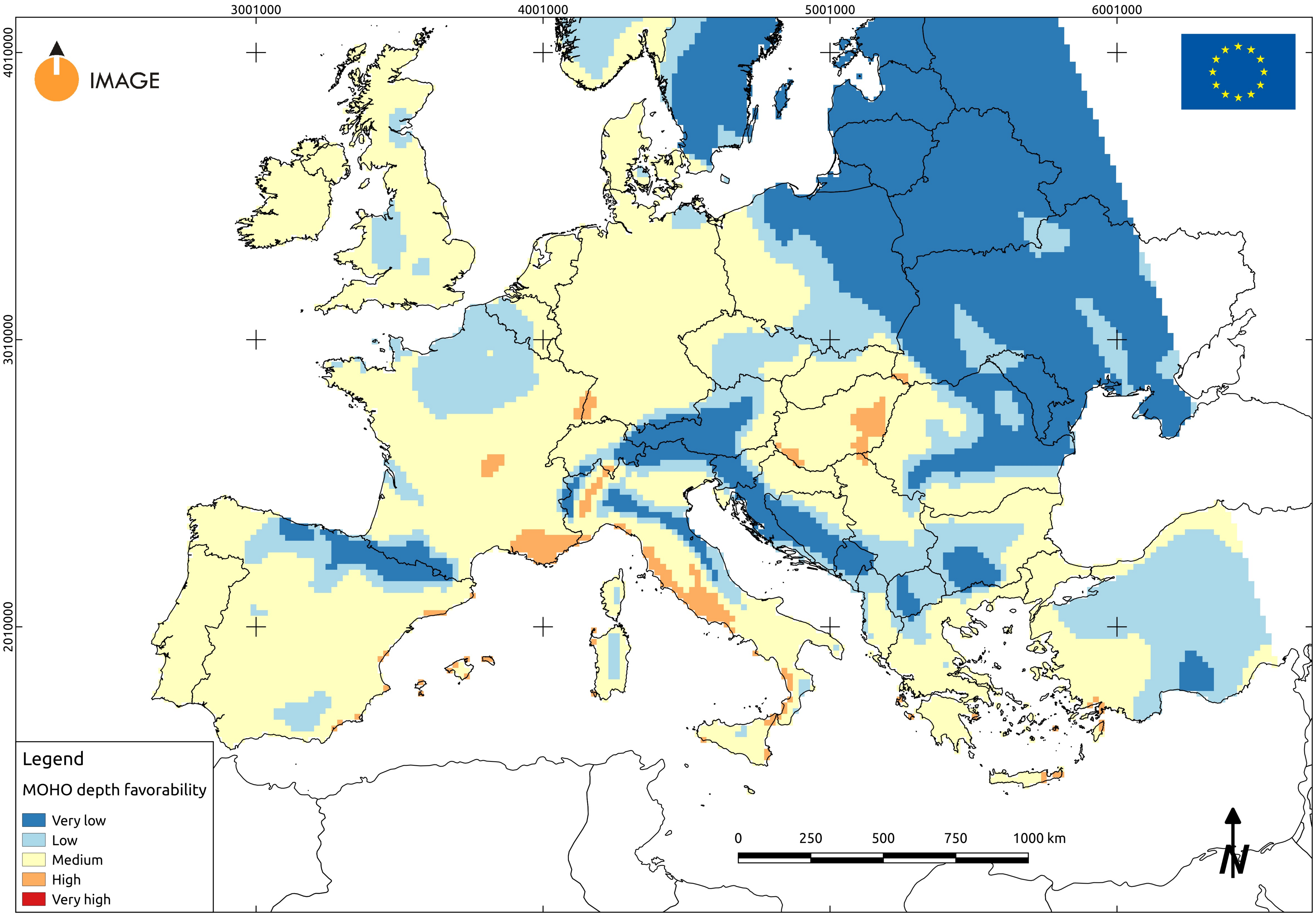
3001000
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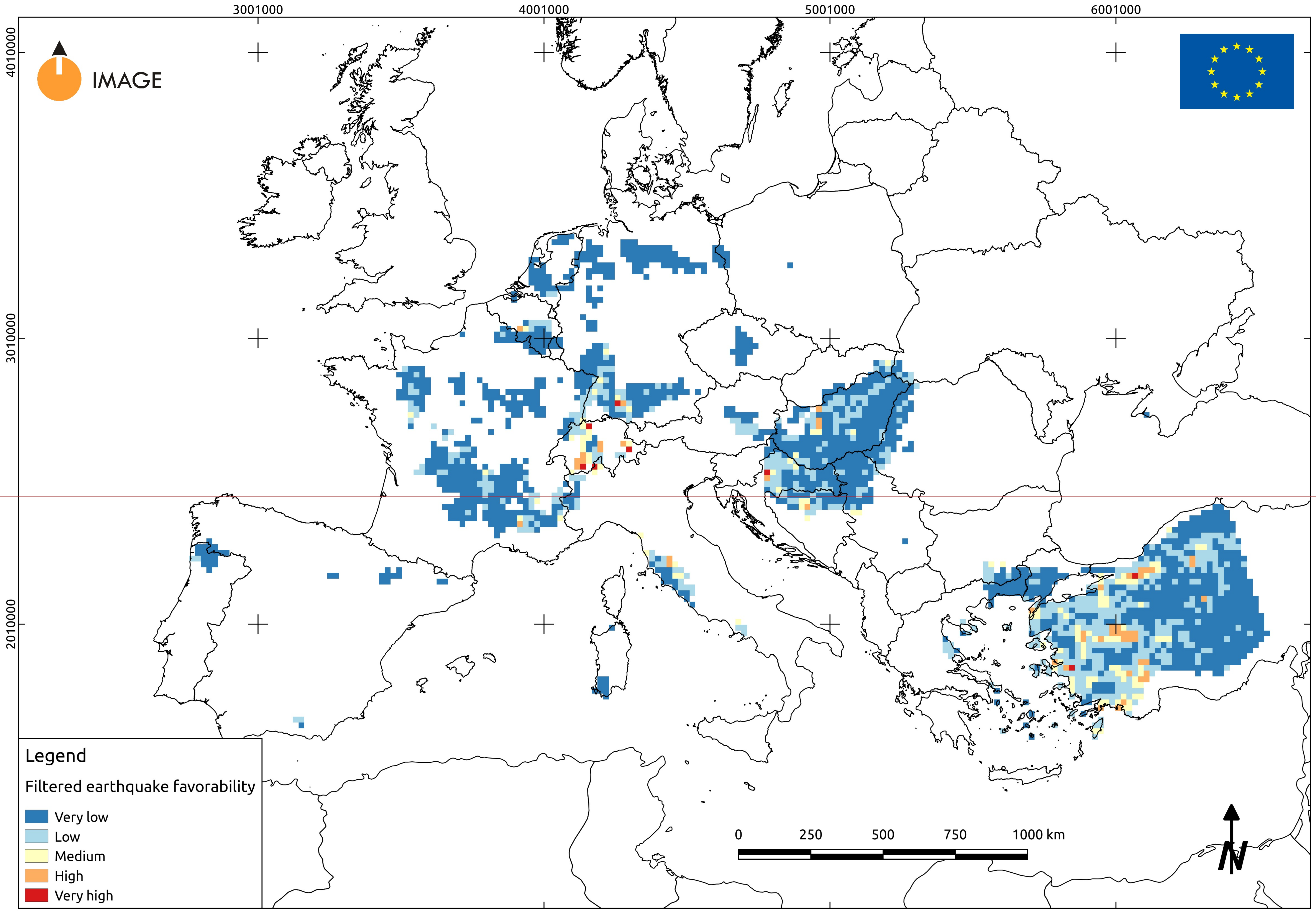
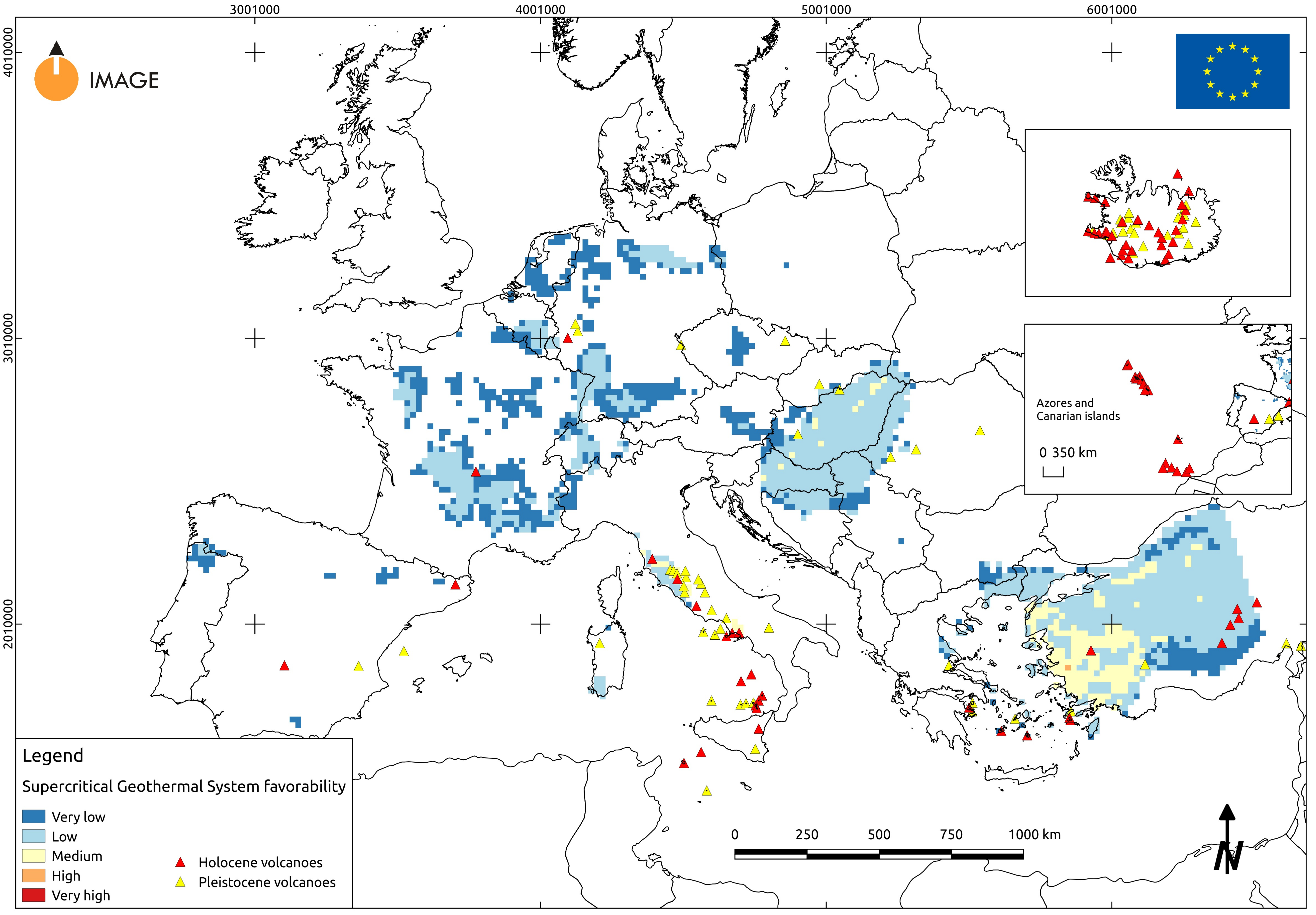
IMAGE
Legend
MOHO depth favorability
Very low
Low
Medium
High
Very high
0
250
500
750
1000 km
N


3001000
4001000
5001000
6001000
4010000
3010000
2010000
IMAGE
Legend
Filtered earthquake favorability
Very low
Low
Medium
High
Very high
0
250
500
750
1000 km
N


3001000
4001000
5001000
6001000
4010000
3010000
2010000
IMAGE
Azores and
Canarian islands
0 350 km
Legend
Supercritical Geothermal System favorability
Very low
Low
Medium
High
Very high
Holocene volcanoes
Pleistocene volcanoes
0
250
500
750
1000 km
N