CHPM2030 Deliverable D6.2.2

Report on PILOTS:

Portugal Iberian Pyrite Belt

Summary:

This report provides an update of geoscientific data and information relating south-west Iberian Pyrite Belt, Portugal, and its relation with EGS potentialities, by updating information and possibilities on the following aspects of a potential CHPM application: underground heat exchanger, production/injection wells, metal recovery, power plant, SGPG, environmental, social, political background, financial, stakeholder requirements. The report also highlights the relevant updates of the 3D geological and geophysical modelling of the Lombador orebody of Neves-Corvo.

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EXECUTIVE SUMMARY

This report provides an update of geoscientific data and information relating south-west Iberian Pyrite Belt (IPB), Portugal. The IPB massive sulphides deposits is a Variscan metallogenic province located in the SW of Portugal and Spain that hosts the largest concentration of massive sulphide deposits worldwide, covering about 250 km long and 30–50 km wide and are associated with volcano-sedimentary sequences present in sea floor environment (http://geoportal.lneg.pt). This geographical area, with particular geological volcanic and sedimentary sequences of Carboniferous and Devonian ages, identified in the southwest of the Iberian Peninsula runs from NW to SE, from Alcácer do Sal (Portugal) to Seville (Spain), and, in the Portuguese side, it covers two active mines: Neves-Corvo mine, owned by Lundin Mining (www.lundinmining.com), and at the Aljustrel mine, owned by Almina (www.almina.pt). For its potentialities and full mining operation with good prospective of increasing in depth the research and exploitation, Neves-Corvo Mine was chosen for test site, to be studied for CHPM purposes, because of its depth of exploitation and undergoing research projects (SmartExploration and Explora UE projects). Because of these projects a deep 3D geological and geophysical model is being reviewed, with old mining data and recent acquired geophysical acquisition, reprocessing and reinterpretation. At the same time, its relation with EGS potentialities will be considered. The Neves-Corvo mine area includes presently 7 massive sulphide ore lenses and is mainly a copper and zinc mine, producing copper, zinc and lead concentrates. The operation is owned and operated by Lundin Mining's Portuguese subsidiary Somincor (http://www.lundinmining.com). Although this mine does not explore any ultra-deep orebodies that allow the application of the CHPM technology yet, prospecting in depth is underway to check for the continuity of the Lombador orebody, so far. Lombador is the deepest orebody that is identified in the Lundin permit area. Geophysical modelling and reflection seismics were conducted under the scope of H2020 SmartExploration (H2020) (https://smartexploration.eu/) and Explora (Alentejo2020) projects and a more refined model will turn out with the available data.

This report will cover the main parameters regarding the feasibility of the implementation of the CHPM technology in Neves-Corvo, that will complement the CHPMD1.2.2. report, namely in the possibility of existence of ultra-deep boreholes in the future and in the geothermal gradient that allows reaching adequate temperatures to produce energy (~70 °C) at relatively shallow depths (~2.5-3 km), compatible with both energy production and metal recovery in the geothermal brine to increase mining production.

An overall look upon the external requirements to the implementation of CHPM technology was studied. Emergent external factors such as energy transition, financial requirements and possibilities, and environmental, social and political backgrounds and future prospects are also referred in the report, as well as possible future agreements between the mining management and the Portuguese government.

Finally, some new data is incorporated into a GoCad 3D model as an update to the GoCad model published in ProMine (EU FP7, Carvalho et al., 2016). This update includes supplementary information, such as deeper and all other recent boreholes information, from 2012 to 2018, to cross-check with geophysical data, reprocessed gravimetric, magnetic, electromagnetic and surface and deep reflection seismic data.

1. INTRODUCTION

This report is part of the tasks of the WP6 of the CHPM2030 “Combined Heat, Power and Metal extraction from ultra-deep orebodies” project, complementing report D1.2.2 Report on pilots and concerns mostly an update of geoscientific data and information relating south-west Iberian Pyrite Belt, Portugal, regarding a 3D geological and geophysical model and its relation with EGS potentialities, for implementing the project. Only in Azores Islands geothermal energy is produced, about 14 GW/y, and a significant part of it comes from the high enthalpy energy produced by the volcanoes. However, Mainland Portugal is geologically different without active volcanism, with geothermal energy produced only in the spa complexes, e.g. for swimming pools, located in the crossing of regional faults. Geothermal is used mainly to house heating and Sanitary Hot Waters (SHW). In the rest of the country geothermal gradient is normal, from about 17°C/km until 30°C/km (CHPM2030 D1.2.2), and adequate temperatures for energy production are only found deeper than 2 km. Some crucial points are focused in this report and their feasibility is discussed. Neves-Corvo and other mines located in the IPB VMS province are indicated in Fig. 1.

As described in the deliverable CHPM2030 D1.2.2, the Iberian Pyrite Belt (IPB) is a Variscan metallogenic province located in the SW of Portugal and Spain that hosts the largest concentration of massive sulphide deposits worldwide (Inverno et al., 2015), covering about 250 km long and 30–50 km wide (

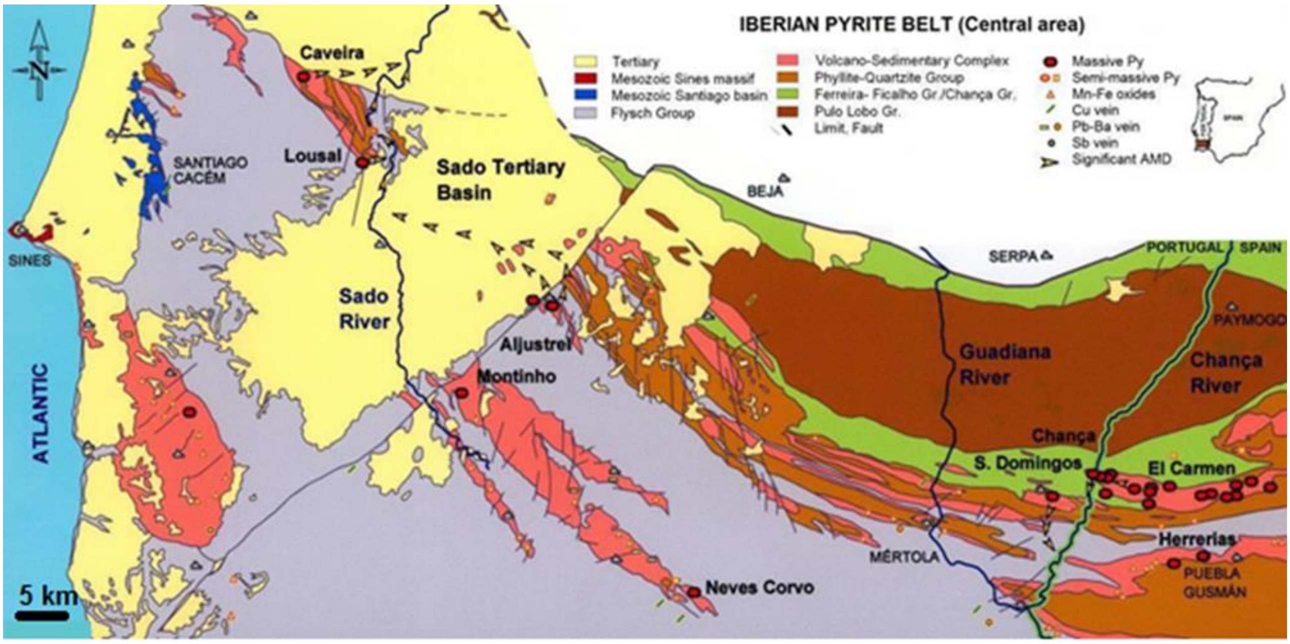

Figure 1). The Neves-Corvo Mine is marked in red. This geographical area, with particular geological volcanic and sedimentary sequences of Carboniferous and Devonian ages, identified in the southwest of the Iberian Peninsula (Oliveira et al., 2013) runs from NW to SE, from Alcácer do Sal (Portugal) to Seville (Spain).

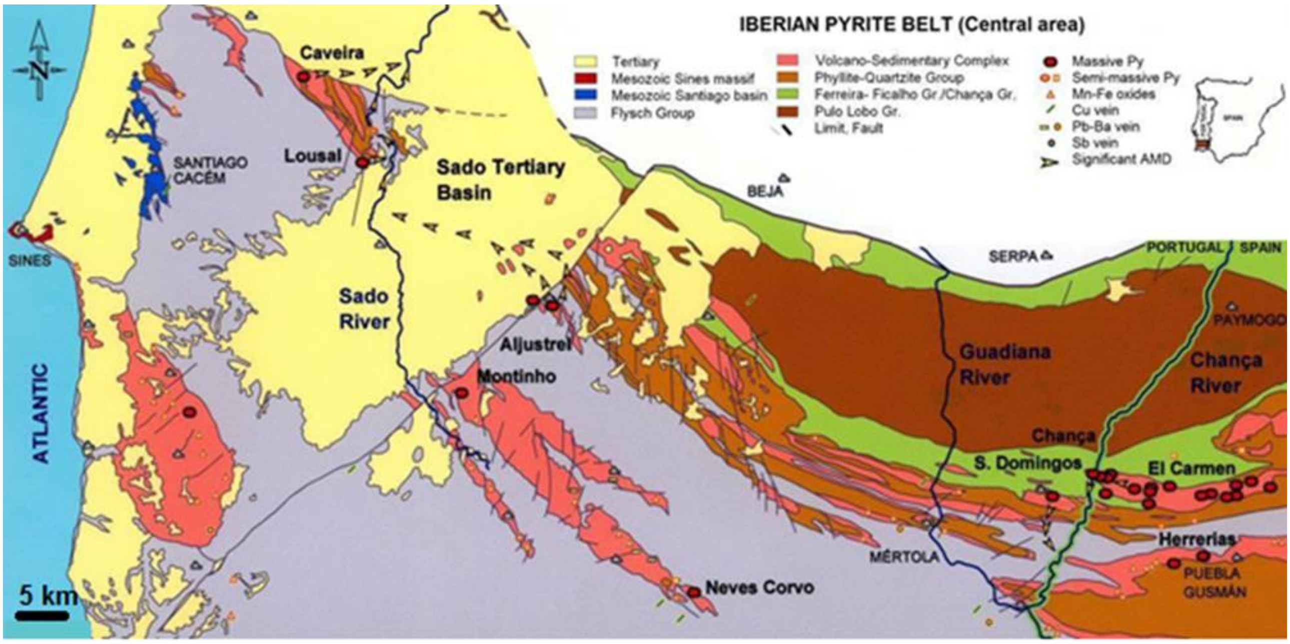

Figure 1. Location of the central area of the IPB Portuguese sector within the scope of the Iberian Peninsula and main geological groups. Location of the IPB massive sulphide deposits and intense acid mine drainage (Inverno et al., 2015, Abreu et al., 2010). Active mining: Neves-Corvo (Somincor-Lundin Mining) and Aljustrel (Almina). Scale (line): 5 km.

Since the 1960's intense geophysical exploration has been done allowing discovering new hidden massive sulphide orebodies (like Neves-Corvo (Albouy et al., 1981, Relvas et al., 2006, see

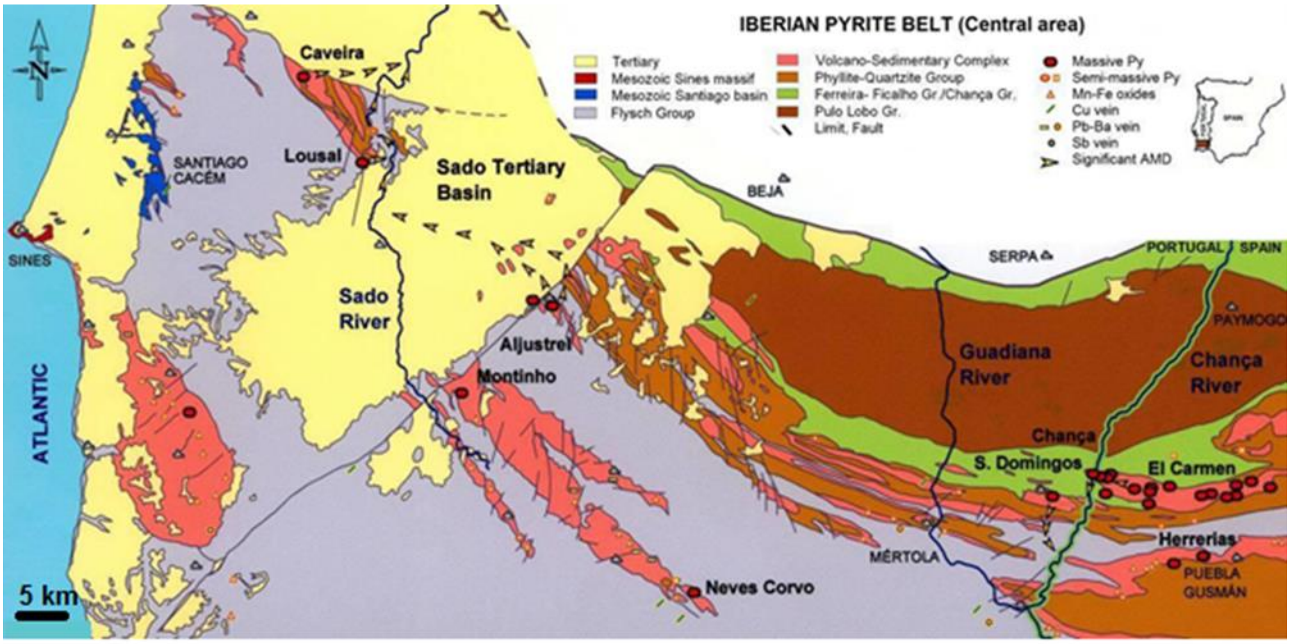

Figure 1), Las Cruces (Doyle, 1996) and Lagoa Salgada (Oliveira et al., 1998)). Schematically, the ore deposits in the IPB are shown in Figure 2.

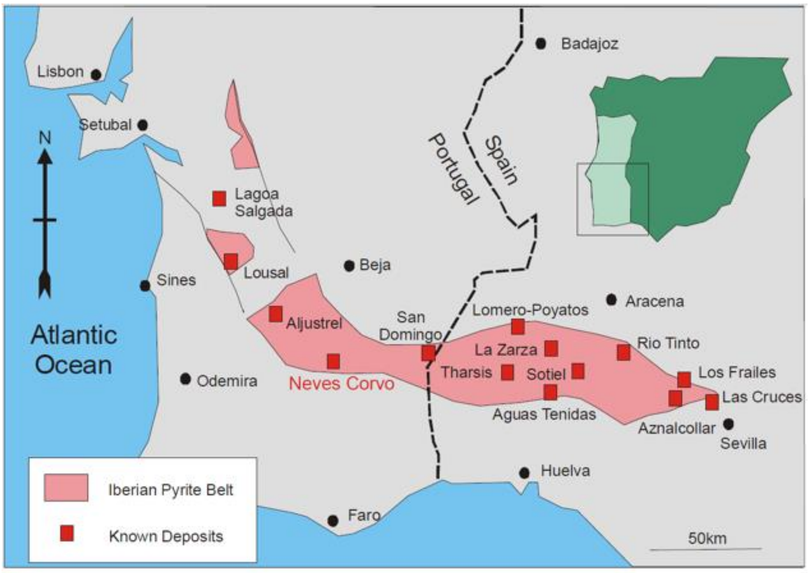

Figure 2. Location of Neves-Corvo and other VMS Deposits within the IPB (www.lundinmining.com).

Finally, an update of geoscientific data and information relating the Mine of Neves Corvo in south-west Iberian Pyrite Belt (IPB), Portugal, is made, regarding the 3D geological and geophysical model and its relation with EGS potentialities, for implementing the project.

2. GEOLOGY

Geology was described in detail in the report CHPM2030 D.1.2.2. Due to the large amount of mineral deposits in southern Portugal (Figure 3) and because of the intensive deep mining prospecting, a dense boreholes network was created, drilled by mining companies (see example of exploration drillhole distribution in the IPB Portuguese sector. Looking at the ore distribution when its overimposed by geology, the considerable amount of mineral deposits are concentrated in some areas with particular features, like identified ore deposits, geological thrusts and the possibility of dipping of knowing ore lenses, as referred in report CHPM2030 D1.2.2 and as seen again in Figure 3.

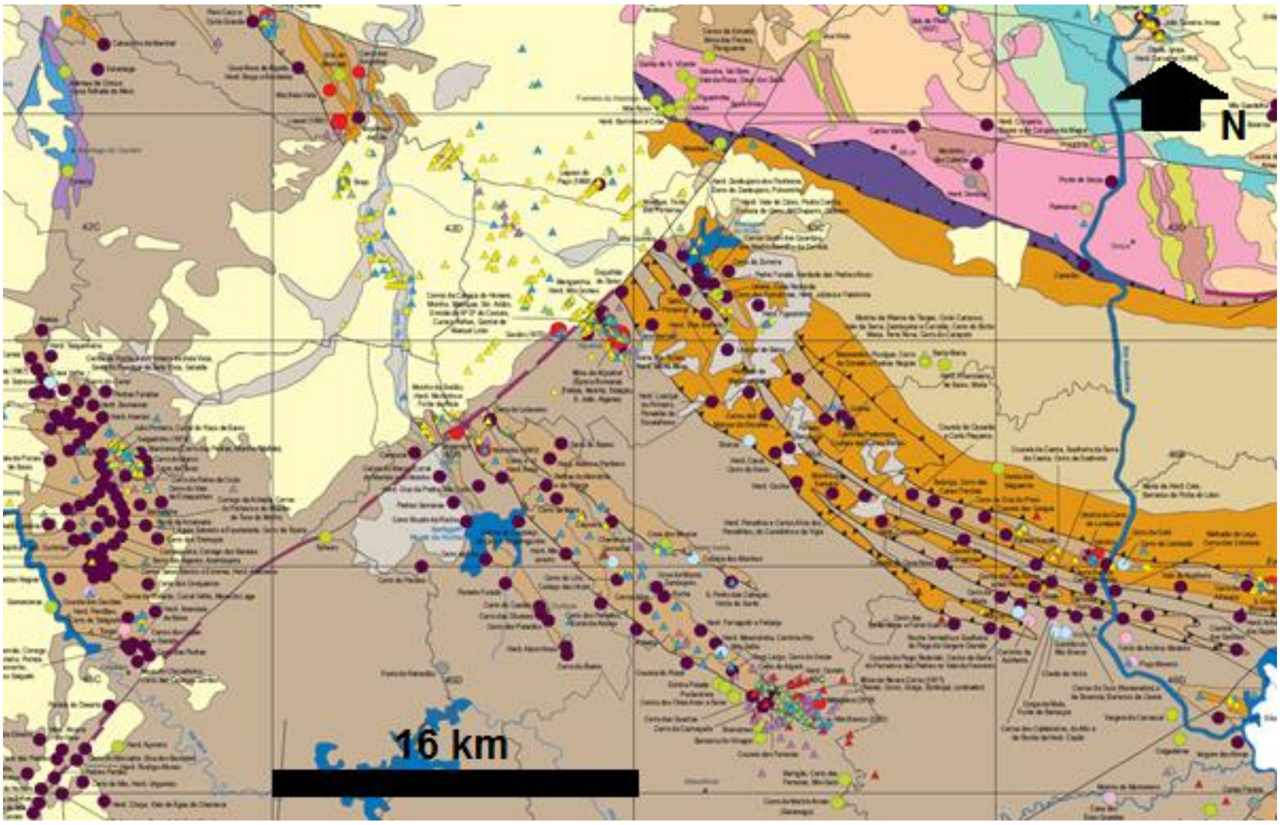

Figure 3. Central area of the geology of the IPB Portuguese sector (ad. Matos and Filipe Eds., LNEG 2013): mineral occurrences - circles: red - massive sulphides, dark purple - Mn, green - Cu, blue – Ba(Pb) and exploration drill holes (triangles). Map grid: 1/25,000 scale maps (16 km x 10 km).

The southern part of the country shows excellent logistics for exploration and mining, namely in the Neves-Corvo Mine. Considering the CHPM2030 objectives, the Neves-Corvo deposit was selected.

Figure 4 shows the geographic distribution of the known ore deposits for this mine deposits as they are known today.

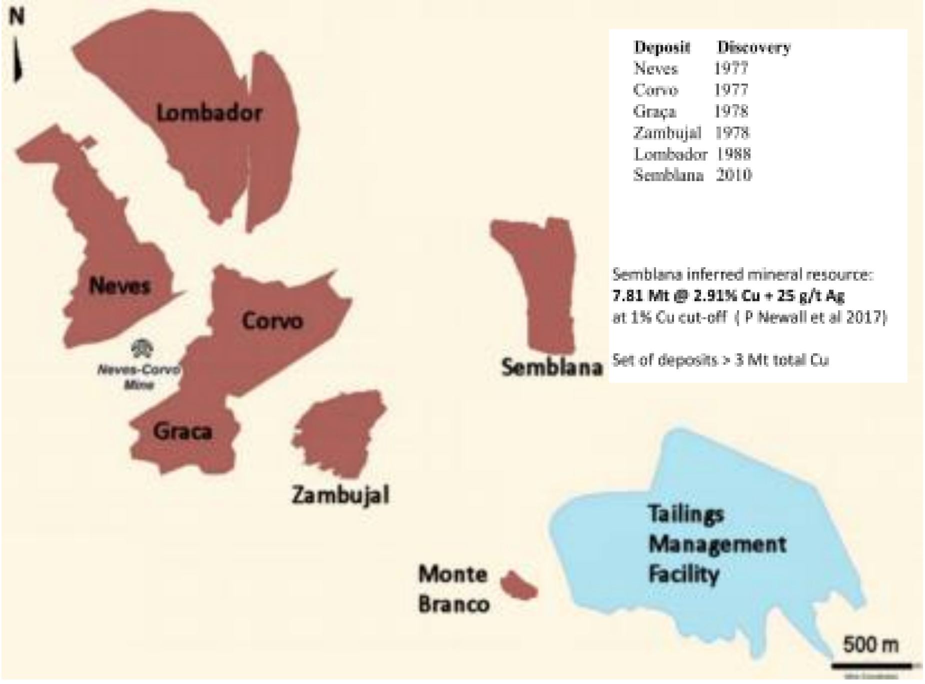

Figure 4. Ore deposits schematic geographic distribution in Neves-Corvo (Scale (line): 500 m).

Neves-Corvo Mine is owned by Lundin Mining who has become a stakeholder for the project, considering the deep mining operations (until 900 m depth) and available exploration drill hole data, until 1,800 m depth in the Cotovio sector, located SE of the Neves-Corvo mine. Selected drill core samples were studied within CHPM2030 and other undergoing projects (EXPLORA and SmartExploration) are conducting a geochemical, geophysical and therefore geological reanalysis, to increase the accuracy of the previous characterization of the improvement of the geological scenario in depth. The model analysis published will be complemented with inferred deep geophysical model, based in the LNEG seismic profiles (data up to 10 km depth) performed in the EU FP7 PROMINE project and Lundin Mining. Some of the new results, obtained in hydrogeologic surveys in Neves-Corvo, and the projects Explora (Alentejo2020) and SmartExploration (H2020) are included in this report. Either Neves-Corvo or Aljustrel mines produce copper ore concentrates from mined massive and stockwork sulphide ores. In the case of the Neves-Corvo mine, zinc and lead concentrates are produced in addition.

To understand the rock-mechanical and geochemical properties of the IPB ore bodies, such as electrical resistivity, thermal conductivity, magnetic susceptibility in basic volcanic rocks with magnetite and pyrrhotite and jaspers with magnetite, rock density in in massive sulphide, stockworks veins and volcanic and sedimentary host rocks and geotechnical properties within the scope of CHPM2030 were carried out in exploration drillhole cores, related with different mineralogical, geochemical and mechanical characteristics of the mineralization and related host

rocks. Different geological scenarios were identified in CHPM2030 D1.2.2 report, considering the presence of sedimentary and volcanic rocks of the IPB Volcano-Sedimentary Complex (VSC) and sedimentary rocks of the Phyllite-quartzite Group (PQG). Considering the IPB geology the following lithological units were considered:

- Mineralization: massive sulphides and stockwork (sulphide vein network);
- Upper VSC sediments - siliceous shales, grey shales, green shales, purple shales, cherts, jaspers and volcanogenic sediments;
- Lower VSC sediments – black pyritic shales, black cherts;
- VSC felsic volcanics (with and without hydrothermal alteration);
- VSC basic volcanics;
- PQG sediments – shales, silts and quartzites, forming the IPB basal siliciclastic basement.

The IPB massive sulphides deposits are associated with volcano-sedimentary sequences present in sea floor environment. Genetic models are present in literature (see for instance Barriga et al., 1997; Leistel et al., 1998; Carvalho et al., 1999; Tornos, 2006; Relvas et al., 2006, Rosa et al., 2008) considering hydrothermal events formed by circulation of sea water in the host rock sequences and later discharge of mineralized fluids. By that time, a Neves-Corvo general geological section was constructed (see figure 5), adapted from Relvas et al. (2006).

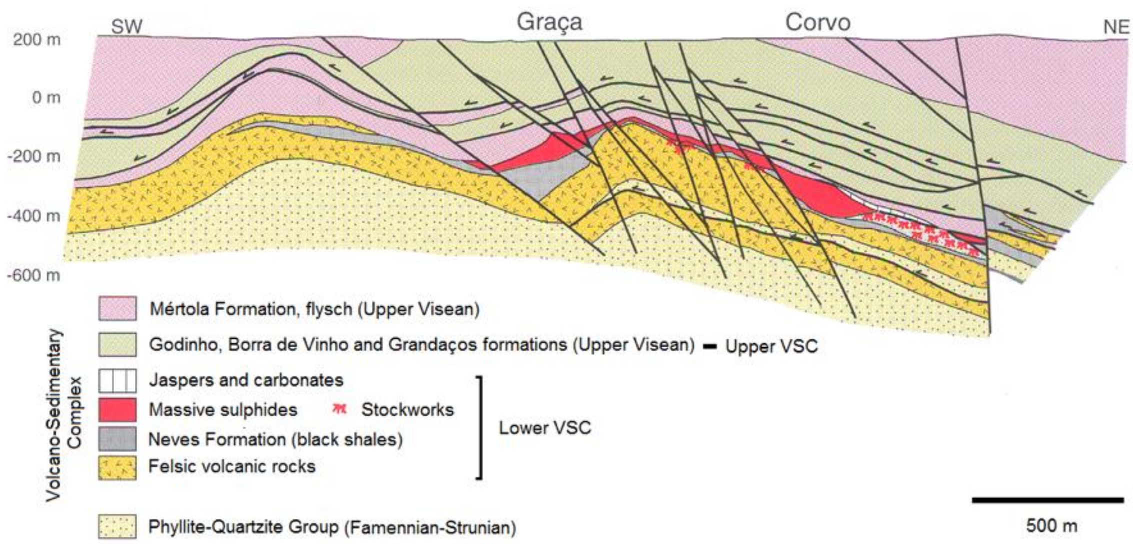

Figure 5. Neves-Corvo general geological section (adapted from Relvas et al., 2006). Location of the lower sector of the Corvo massive ore lens (blue arrow).

Regional and hydrothermal alteration occurs, the second represented by silica and chlorite in the inner zones and silica + sericite in the external zones. A significant number of deposits is directly associated with felsic volcanic rocks formed in the late Devonian (Matos et al., 2011) and early Carboniferous (Barrie et al., 2002; Tornos, 2006), see Neves-Corvo section, figure 5. The deposits generally present a lenticular shape with up to 2 km of length and thickness usually < 150 m. The stockwork structures are commonly present in the root of the hydrothermal system. Variscan tectonics can change the original geometry by folding and faulting, including thrust generation, promoting the existence of complex structures. The deposits are formed mainly by massive pyrite. Other minerals occur like chalcopyrite, sphalerite, galena and sulphossalts locally with economic importance. Present near mining exploration projects, like the Lundin Mining Neves-Corvo DGEG Exploration Permit Area, are being developed and focused in the research of new metal rich massive and stockwork mineralizations and LNEG is cooperating with them.

The next chapter will show in detail the geophysical methods that were applied to get this new geological cross-section of the Neves-Corvo area. However, geophysical magnetic and gravimetric inversion along with borehole lithology to provide calibrations was very important to construct a 2D geogilocal model. According with these new geophysical processed data and with the data from CHPM2030 D.1.2.2, the 2D model for the Neves-Corvo ore based on geology and the response of magnetics and gravimetric data is represented in figure 6.

As described in report CHPM2030 D1.2.2, the IPB regional structure is conditioned by a SW tectonic vergence. Globally, the geological structures present an E-W direction in Spain and close to the Portuguese/Spanish border and a NW-SE direction in the western Portuguese IPB sector. Several complex antiforms are defined, forming VSC-PQG outcropping lineaments (see in the Portuguese sector the 1:200,000 SGP geological maps, Sheets 7 and 8, Oliveira et al., 1988 and 1992, Oliveira et al., 2013, Inverno et al., 2015). These structures are present in depth, under Flysch BAFG sediments and/or Cenozoic age sediments (*e.g*. Sado Basin, Oliveira et al., 1998). In the northern IPB regions allochtonous structures are dominant. In the southern IPB branch the complexity is lower.

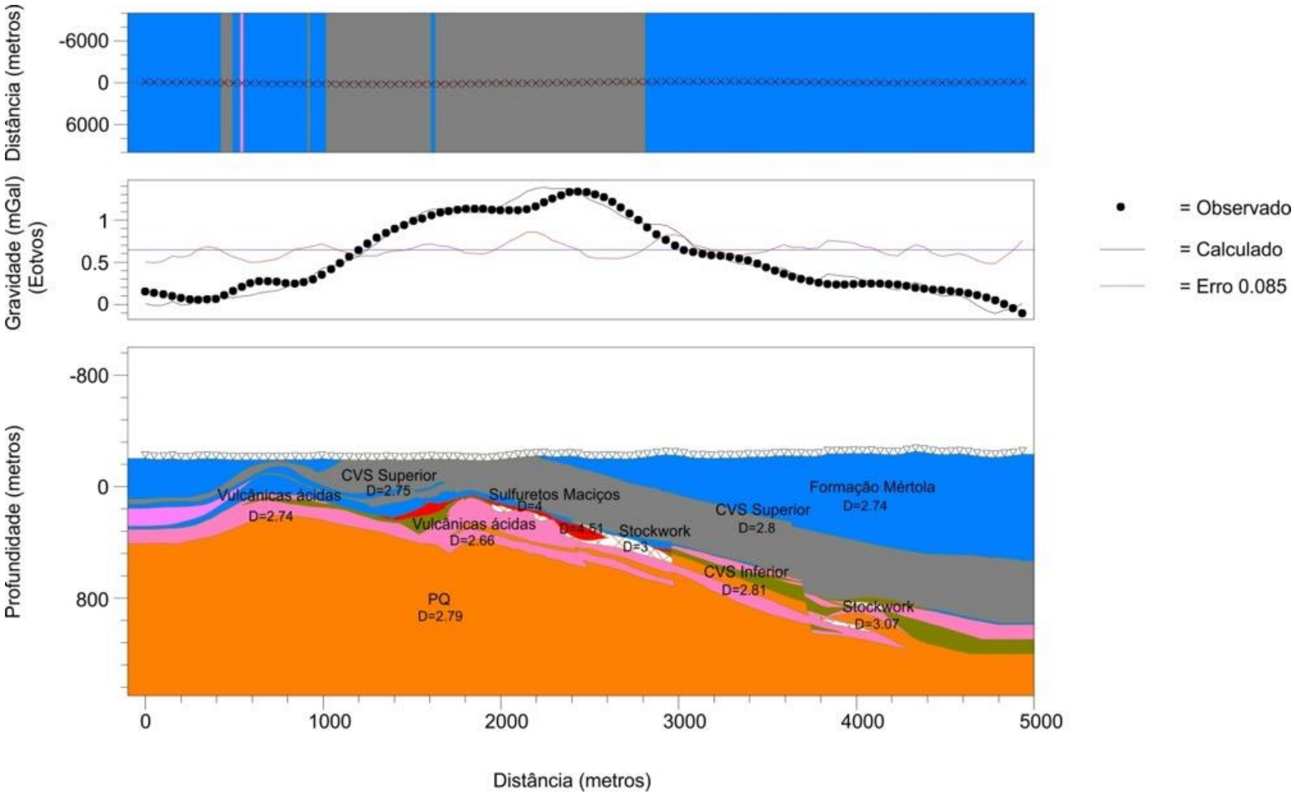

Figure 6. 2D geological model of Neves-Corvo ore body based on gravimetric inverted data. Orange: PQ; Pink: Vulcânicas ácidas (acidic volcanic); Green: CVS inferior (Lower CVS); Red: Sulfuretos Maciços (Massive Sulfides); White with crosses: Stockwork; Blue: Formação de Mértola (Mértola Fm); Grey: CVS superior (Upper CVS);

3. NEW GEOPHYSICAL ACHIEVMENTS IN THE IPB

The LNEG EXPLORA/Alentejo2020 research project promoted recently regional geophysical mapping focused in the IPB Portuguese sector.

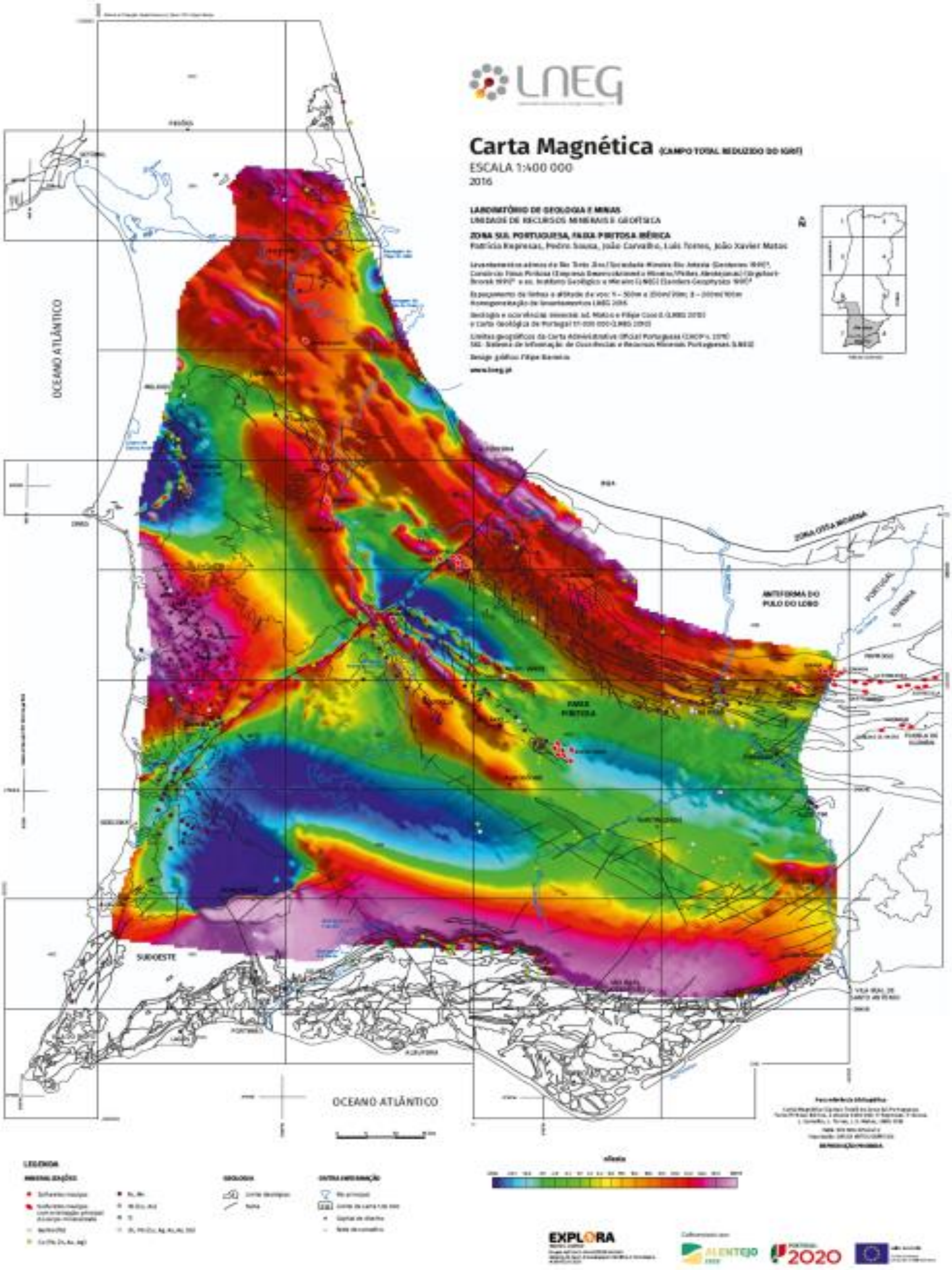

Figure 7. Magnetic (Total field IGRF reduction) South Portuguese Zone 1/400,000 scale maps, Represas et al., LNEG 2016, EXPLORA/Alentejo2020 Project.

These maps allow a better understanding of the Volcano-Sedimentary Complex structures and lineaments (Matos et al. 2018; Batista et al., 2014; Represas et al., 2016).

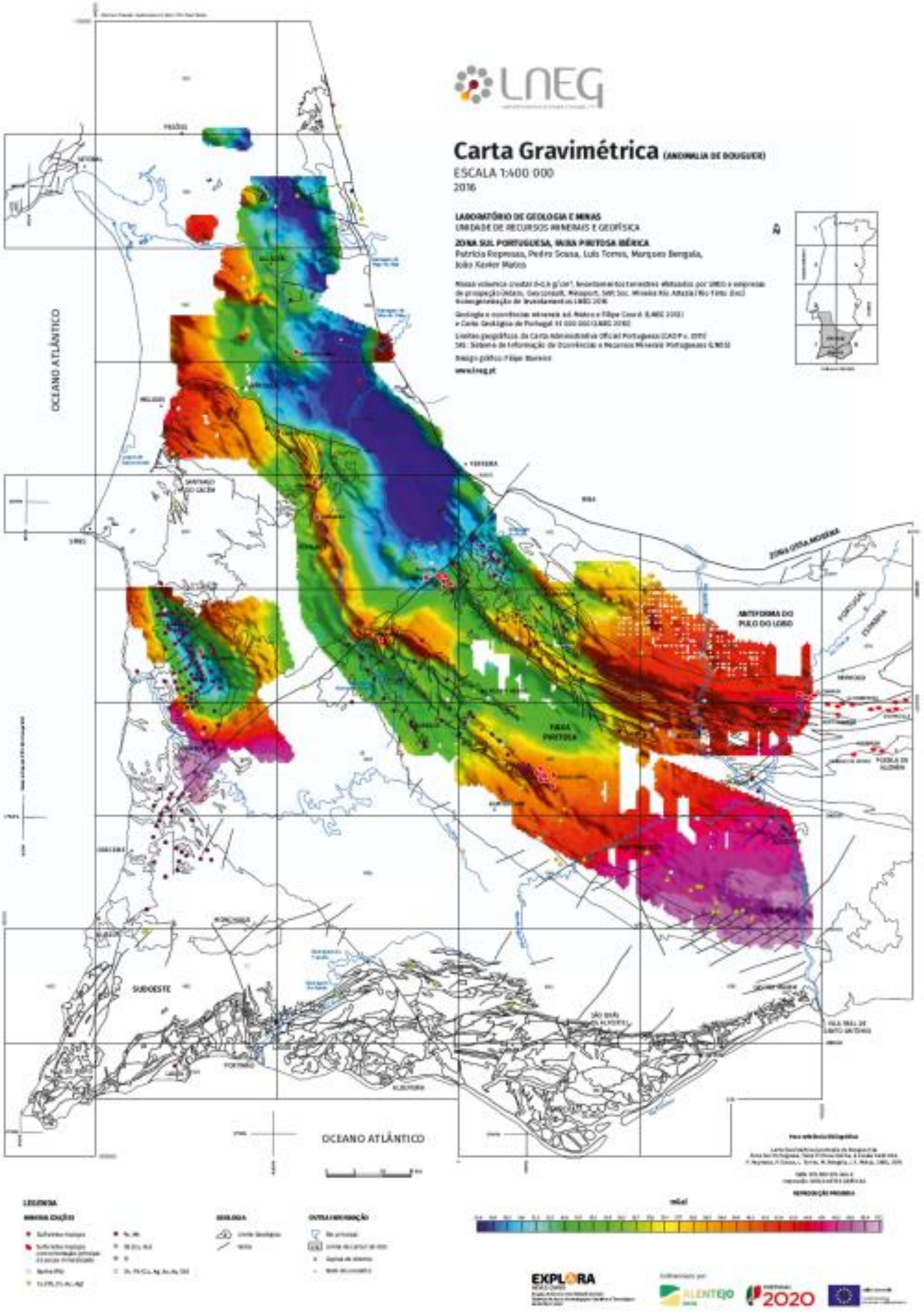

Figure 8. Gravimetry (Bouguer 2.6) South Portuguese Zone 1/400,000 scale maps, Represas et al., LNEG 2016, EXPLORA/Alentejo2020 Project.

Magnetic (Total field IGRF reduction) and Gravimetry (Bouguer 2.6) South Portuguese Zone 1/400,000 scale maps were released (Represas et al., 2016), in the EXPLORA/Alentejo2020 Project are represented respectively in figures 7 and 8.

These maps are the homogenization of decades of airborne and regular field surveys.

The map in figure 7, showing the total magnetic field with IGRF reduction clearly shows some features, from which can be highlighted the long dike related with the Messejana regional fault, that crosses the entire map in the NE-SW direction. Neves-Corvo is located in the edge of the Rosário anticline, seen in the magnetic map with a negative anomaly reaching about -15 nT. The same area corresponds to a strong gravimetric anomaly, as seen in figure 8. 3D models of the residual Bouguer Anomaly Map from Neves-Corvo have been constructed.

Aerospectrometry of the study area, Scale 1:50.000, is represented in Figure 9.

The area has more than 204,000 drillhole densities, 163 magnetic susceptibilities measurements in outcrop, 5500 measurements of magnetic susceptibilities in drillhole and about 60 electrical conductivities measurements in outcrop.

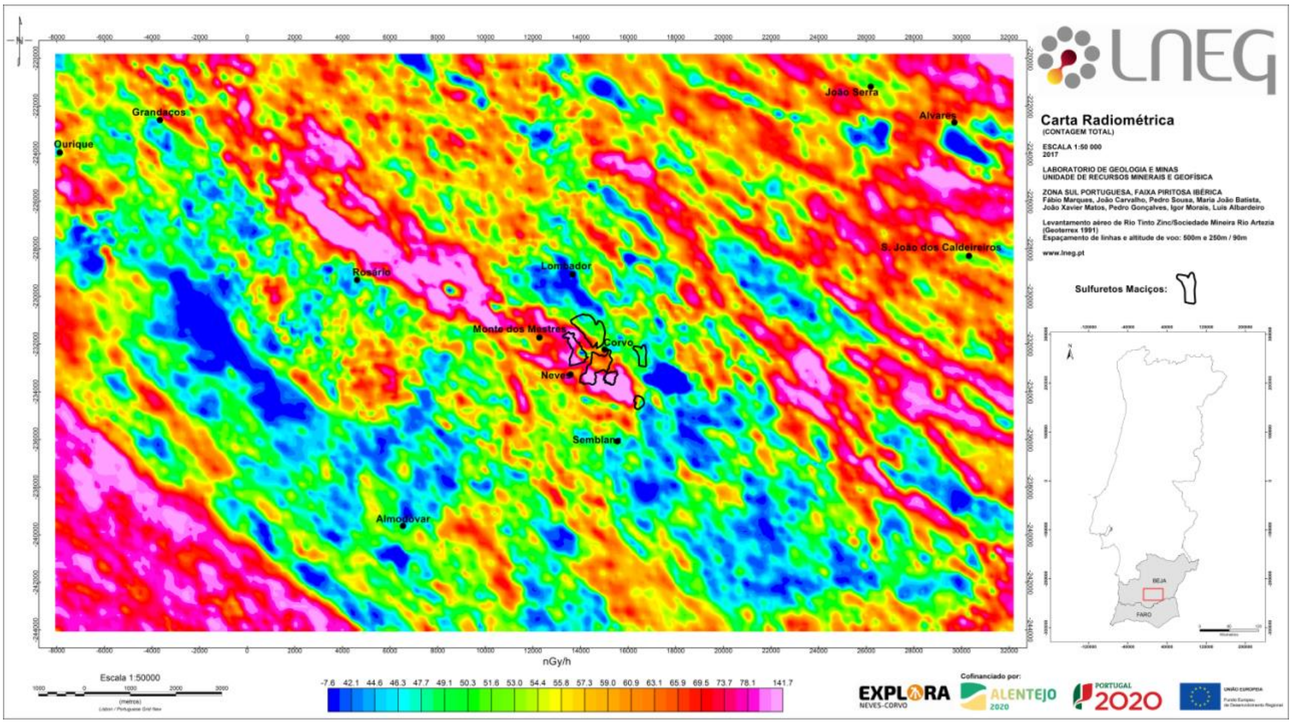

Figure 9. Aeroradiometry (Total Count) of the study area. Scale 1:50,000 the orebodies projection at surface (Courtesy of Explora project, F. Marques, LNEG 2018).

The 2nd vertical derivative of the gravimetric map was used in Neves-Corvo to highlight low wavelength anomalies related small orebodies. The aeroradiometry of the study area shows a surface weakness in Total count related with the presence of large areas covered with shales and greywackes flysch sediments of the Mértola Formation. Outcropping VSC felsic volcanic rocks are reflected by intense anomalies (Total Count) Neves-Corvo. The three types of data were plotted in 2D SW-NE cross-section (figure 10).

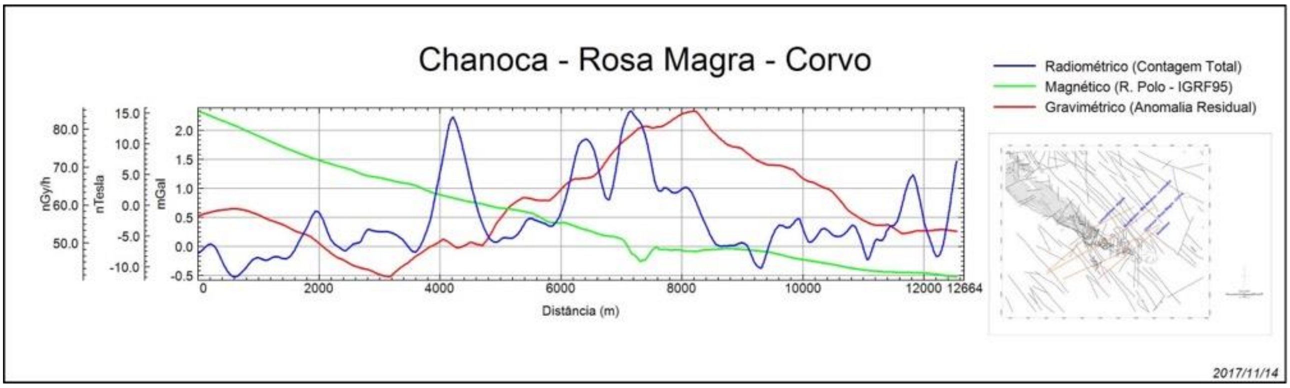

Figure 10. Response of gravity, magnetic and aerospectrometric data for Neves-Corvo orebody (courtesy of Explora project, F. Marques, LNEG 2018).

The 3D location of the known massive ore bodies in the Neves-Corvo mine is the one depicted in Figure 11 (Lundin Mining). The ore lenses present a lenticular shape like other IPB VHMS deposits. The ore lenses located near the surface are directed linked with the Neves-Corvo gravity anomaly (Leca 1983, Carvalho et al., 1999, Matos et al. in press, Explora Project, 2018).

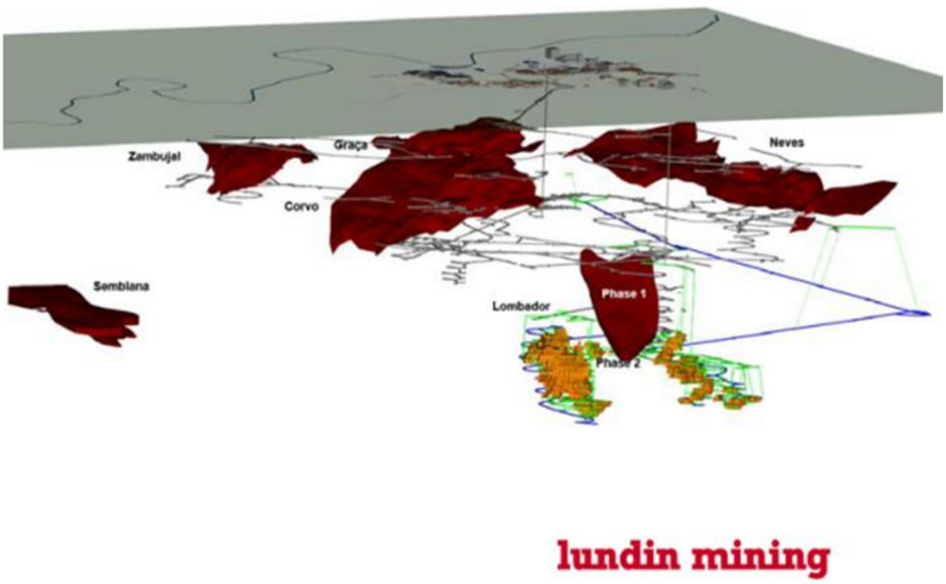

Figure 11. 3D location of the known ore bodies in Neves-Corvo (Lundin Mining).

Metal zonation can be correlated with rock density as shown by the 3D geochemical and gravity inversion maps of the Corvo and Graça ore lenses in figure 12 (Batista et al., 2014). Even though the calculated geochemistry and density models indicate that the places where high rock density and high Cu concentration coincide, are places where the predictability values are considered to be the highest. This corresponds to the known massive sulphide ore lenses.

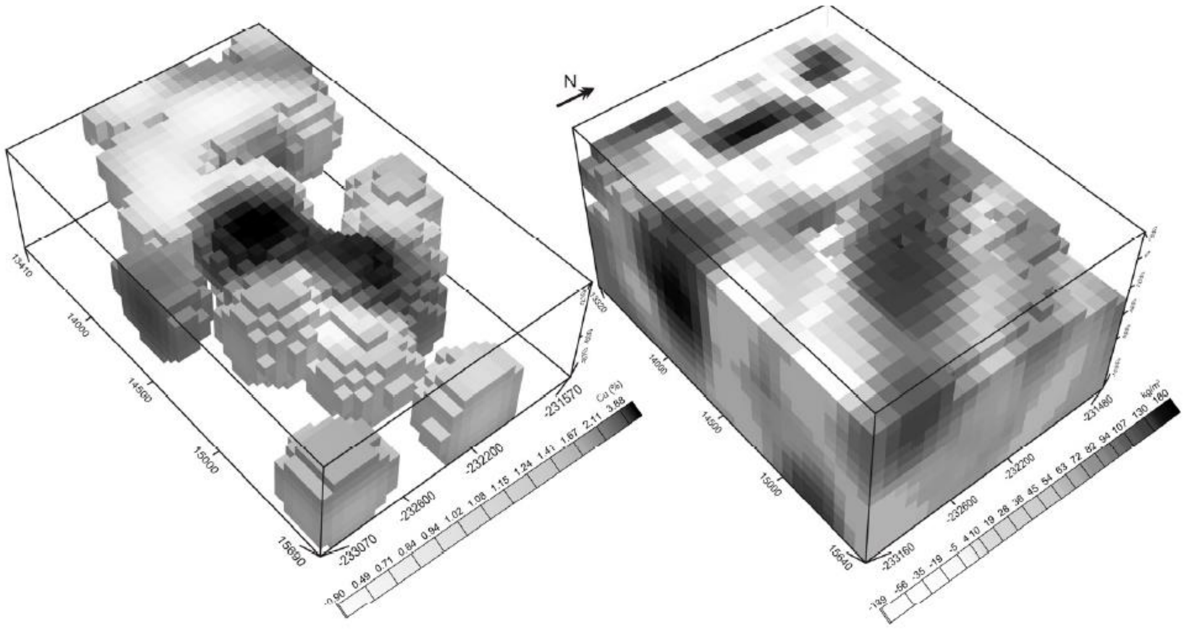

Figure 12. Neves-Corvo 3D geochemical and gravity inversion model (Batista et al. 2014).

Some gravimetric anomalies (residual anomaly) were located at the Neves-Corvo orebody were 2D modelled (figure 13).

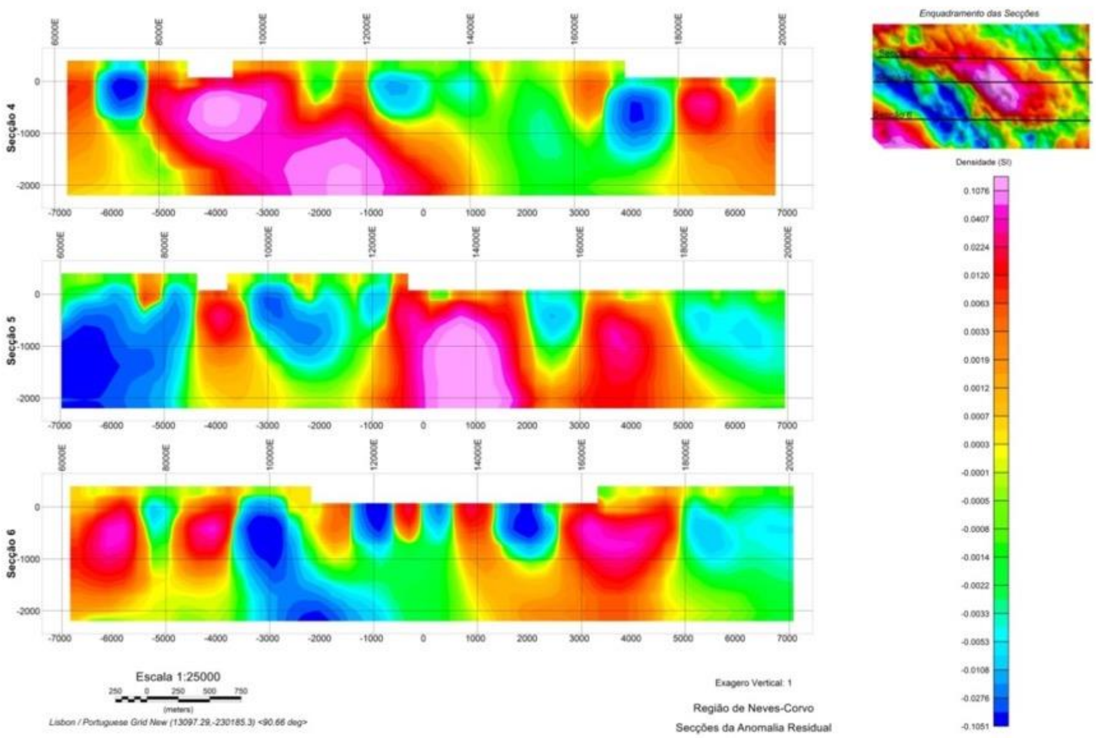

Figure 13. 2D gravity models of the Corvo sector of the Neves-Corvo mine. Sections of Residual Anomaly (courtesy of Explora project, F. Marques, LNEG 2019).

2D modelling showed higher density materials in the area of the orebody masses that dips about 45°SW towards depth and show good prospective of deepening of those materials below the 200 meters depth. In fact, the 2D modelling of the residual gravimetric anomaly shows several denser masses in depth that are coincident with the presence of identified orebodies.

As seen in figure 13, the 2D geological model of Neves-Corvo orebody based on gravimetric inverted data shows the presence of mineralized stockwork located deeper than 1000 meters. Reflection seismics conducted inside the mine at 600 m depth at the moment of this report will allow us to compose the 2D geological model as the identified reflectors will be visible in depth or not (Project SmartExploration, H2020 budget, Lundin Mining current exploration program).

4. DEEP METAL ENRICHMENT

In each massive sulphide orebody metal zonation occurs related with the hydrothermal system developed in the area. Commonly hanging walls present high values of Zn and Pb, while footwall areas are copper rich. The stockwork mineralization present a particular metal zonation

distributed in different host rocks that include VSC felsic volcanic rocks and sediments (Neves and Corvo formations) and the basal siliciclastic unit the Phyllite-Quartzite Formation (Relvas et al., 2006; Oliveira et al., 2013). The Neves-Corvo metal zonation can be observed in the map of the figure 14.

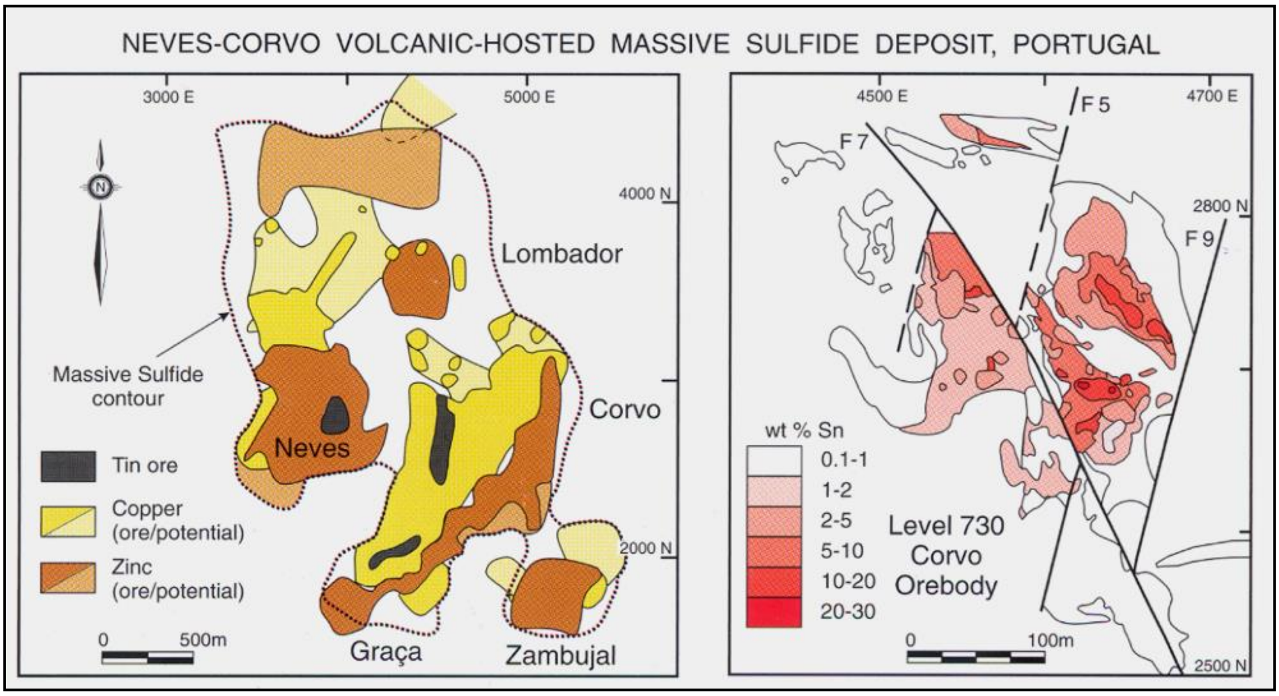

Figure 14. Metal zonation maps of the Neves-Corvo deposit (Relvas et al. 2006, SEG).

As mentioned before, the Neves-Corvo mine area includes presently 7 massive sulphide ore lenses. The 3D location of the known ore bodies in Neves-Corvo is the one depicted in figure 15.

Further work of the Promine Project is allowing correlation between seismic reflectors and conductive bodies TEM, thrust faults and orebodies, improving therefore the knowledge in depth of the study area.

These 3D geophysical models are being improved as new data are being acquired. The 3D models include new reflection seismics surveys at ~-600m, TEM modelling, gravimetric and magnetic modelling.

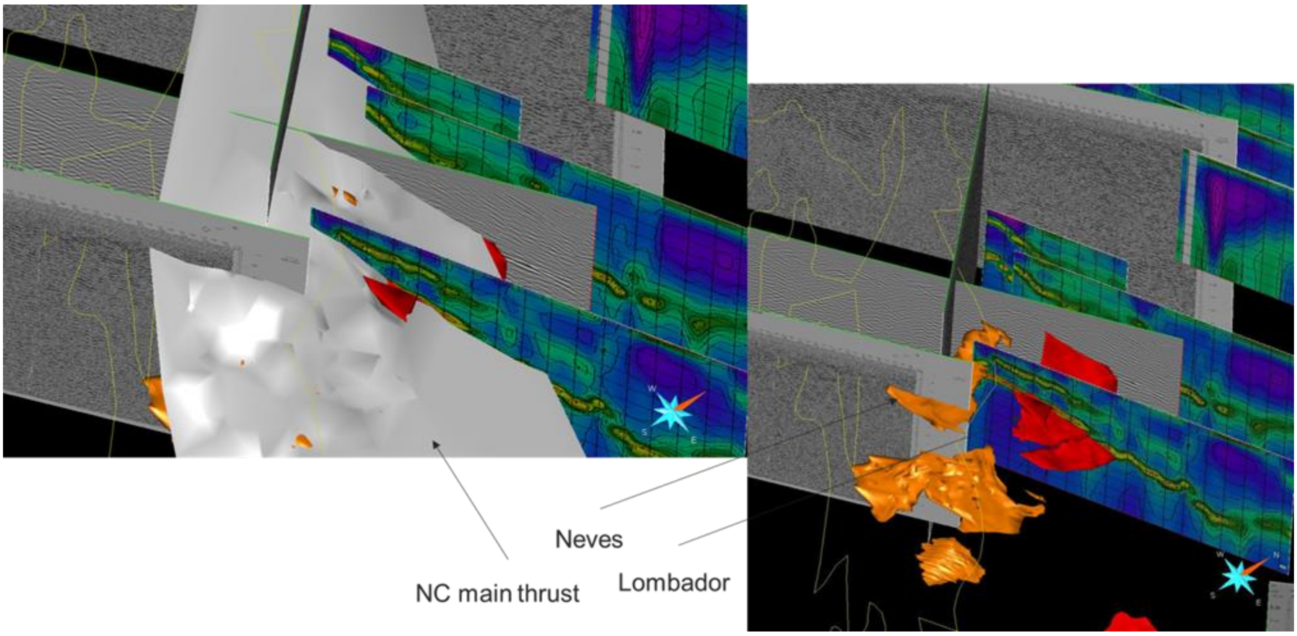

Figure 15. Improvement of the 3D geophysical models of the PROMINE Project, showing EM conductors in deep and massive sulphide mineralization (Courtesy of Smart Exploration project).

Regarding electromagnetic (TEM) data, the profiles are being reprocessed so that a 3D model is being built within the scope of SmartExploration to integrate other sources of information (Figs. 15 and 16).

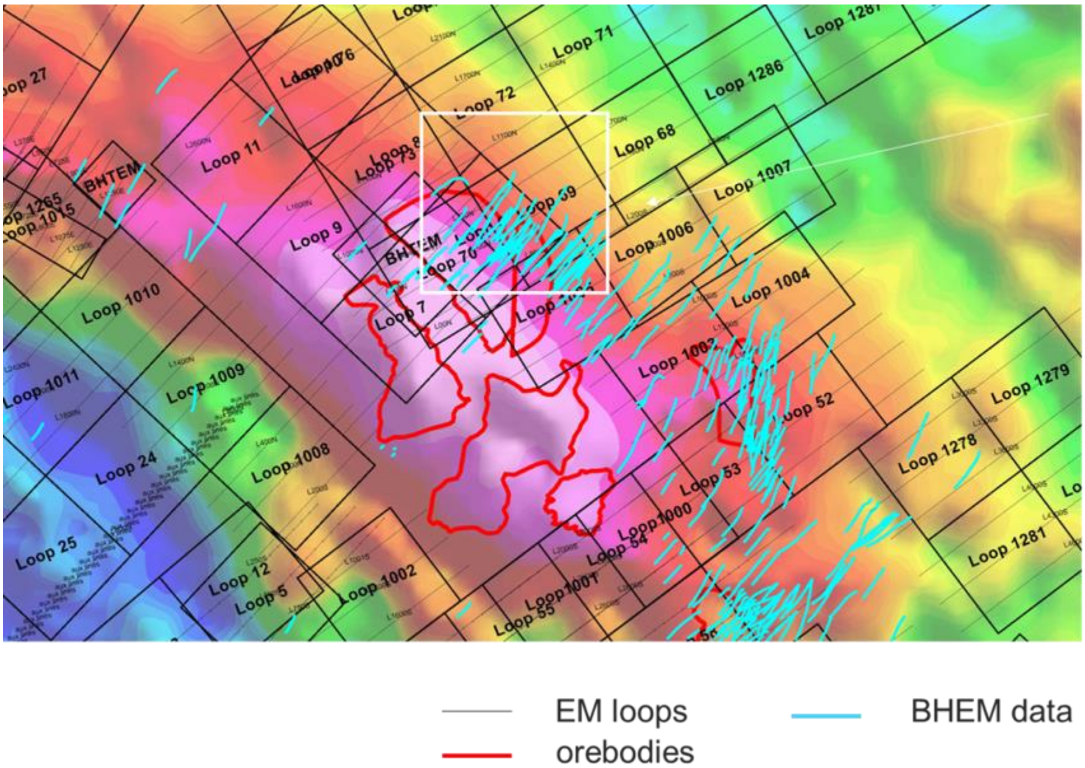

Figure 16. EM profiles and loops carried out in Neves-Corvo Mine permit (Courtesy of Smart Exploration project).

Geophysical seismic surveys conducted in the Promine project show a deep-rooted faults (> 5 km) that controls the Paleozoic basement block units, like in the case study of Cotovio (Carvalho et al., 2016, see figure 19). These fault systems can promote deep water circulation and eventual metal leaching in depth. In the Neves-Corvo mine region several copper veins are present, related with late-Variscan strike-slip faults, like the Brancanes, Porteirinhos and Barrigão old mines (Matos et al., 2003; Reiser et al., 2011, Fig. 18). These veins present chalcopyrite + pyrite + sulphossalts associated with quartz and carbonates.

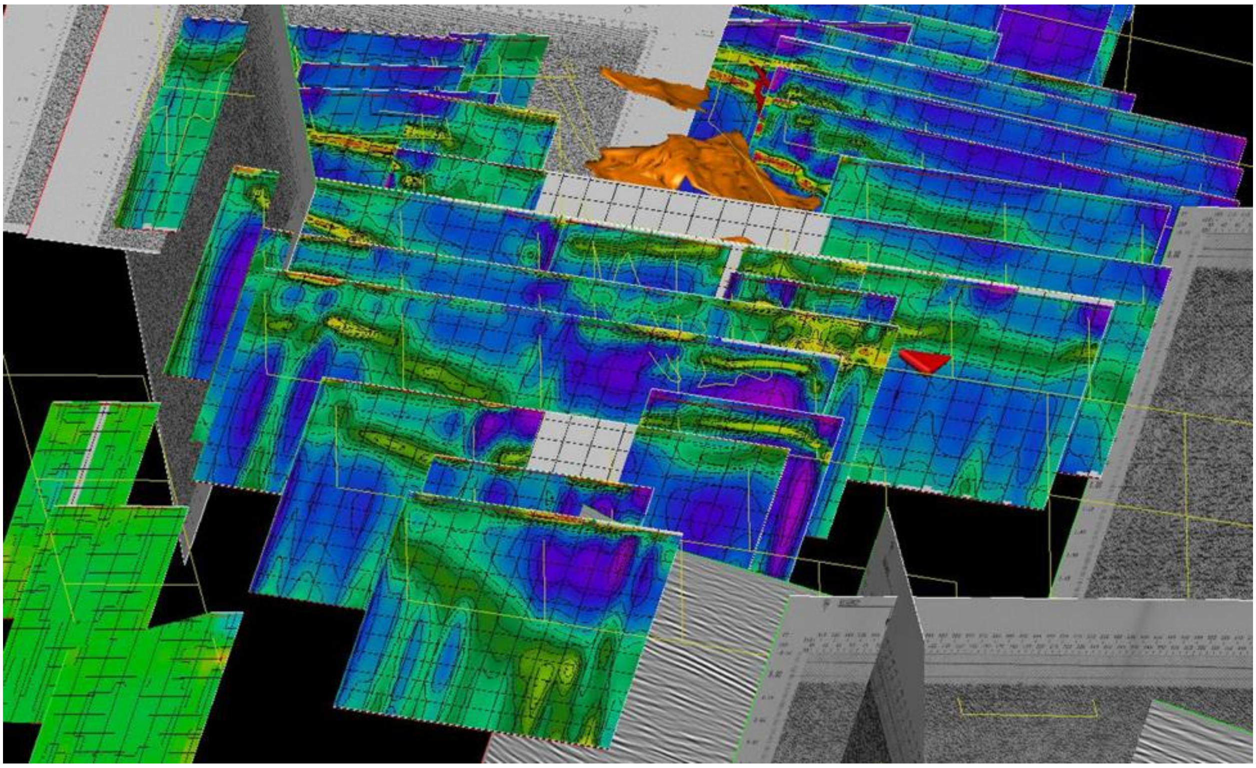

Figure 17. TEM profiles and loops carried out in Neves-Corvo Mine permit (Courtesy of Smart Exploration project).

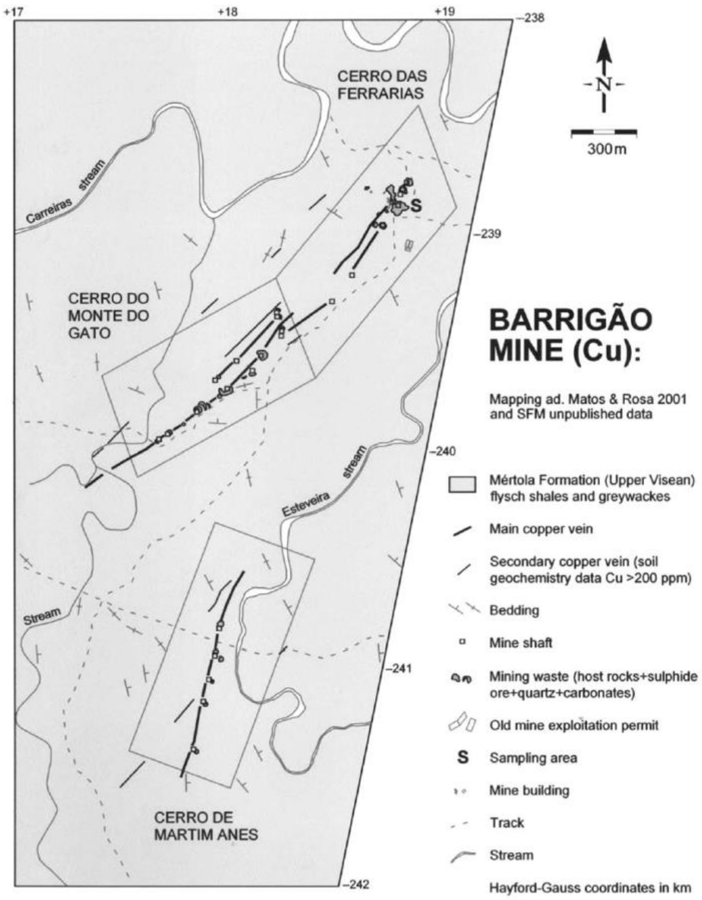

Figure 18. Structural map of the Barrigão copper mine, SE of Neves-Corvo (in Reiser et al., 2011)

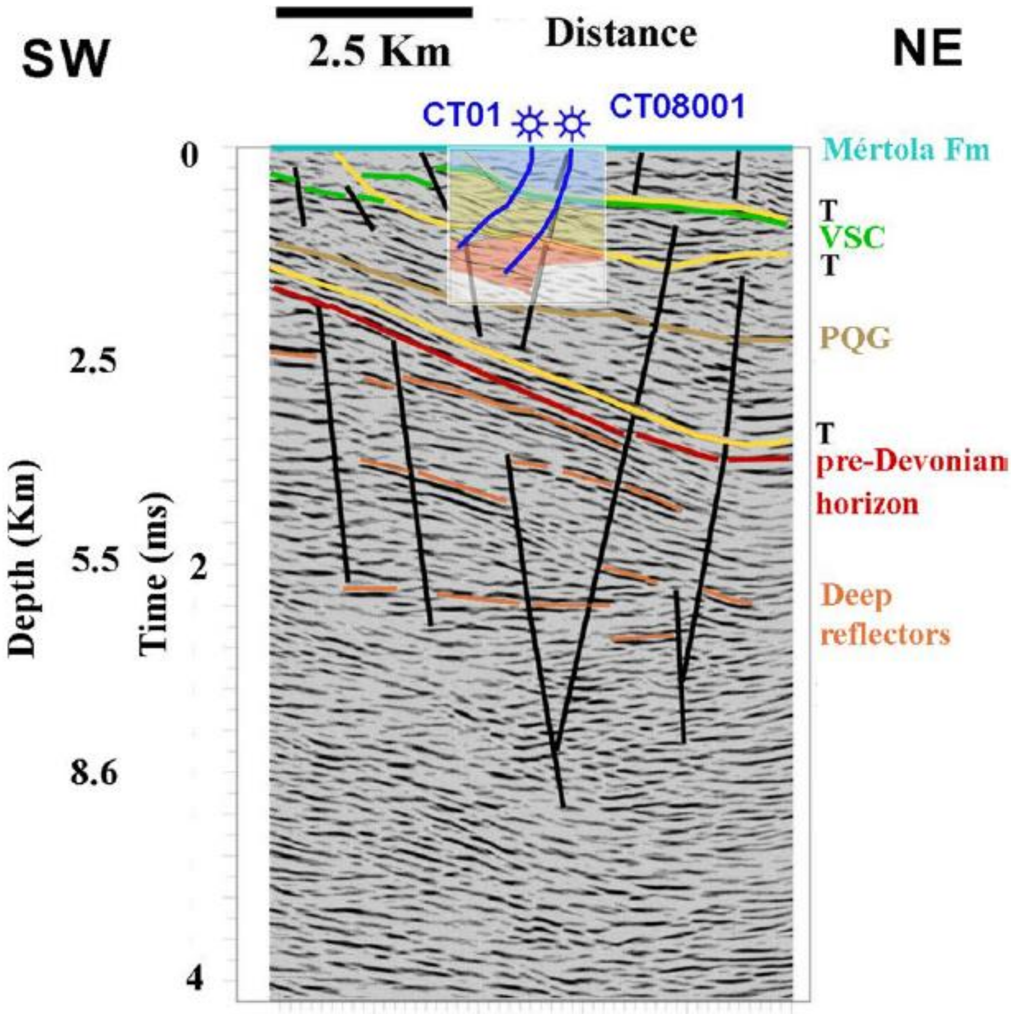

Figure 19. Deep late Variscan faults reflected in seismic surveys, performed at the Cotovio sector, SE of the Neves-Corvo mine. Boreholes CT01 and CT8001 cut the mineralization and are being used to calibrate time domain electromagnetics (TEM).

5 EGS POTENTIAL

The economic feasibility of EGS projects in the IPB jointly used to generate combined heat and metal extraction can indeed be a reality. Some studies consider that, with adequate investment in research and development over the next few years, EGS technology will become competitive and an important contribution to the energy-mix by 2050 or even earlier and if metals would be extracted at the same time, it would be a competitive advantage.

5.1 Hydraulic properties, deep fluid flow

According with Batista (2003), water pumping tests performed in the Neves-Corvo IPB area (See Fig. 1) and surroundings, conducted by Bertrand et al. (1982) in eight wells with maximum depth of 261 m and drill holes with depths ranging from 100 to 645 m, and concluded that drawdowns to

the nearby wells range between 0.88 and 21.6 m and to the drillholes directly between 6 and 43.4 m. Transmissivities have values respectively of between 9.1 x 10^{-6} and 1.1 x 10^{-4} to the wells and between 1.86 and 64.6 x 10^{-6} m^2/s to the drillholes. (Batista, 2003). This is representative for the upper aquifer. For the intermediate and deeper aquifers hydraulic parameters are not available, since they reflect the interest of the company in orebodies and groundwater studies are not the major priority.

In the Variscan Massif terrains (north and centre of Portugal) the permeability is higher, reaching dozens of meters per second and is associated to fracturing zones. In these fracturing zones, decompression and terrain alteration allow a permeability that averagely ranges from 0.1 and 2 x 10^{-6} m/s. At bigger depths, and away from the fracturing zones, permeability diminishes, and is lower than 0.01 x 10^{-6} m/s.

Some conclusions could be taken from these hydrogeological data:

1. The possibility to find an important aquifer in this compact unit pile with low permeability and with low effective porosity is very low.
2. The deep fractures opened to water circulation are found in the top of the pyrite ore lenses, in the flysch greywackes from the base and not in the interior of the sulphide ore. These greywackes show more permeable fractured zones that, instead, can make groundwater circulation easier. Its depth depends on the orebody. Lombador, the orebody in study, here has an indicated downward continuation.

This last conclusion may be important, if these more permeable zones are near the sub-vertical faults that put the sulphide ore in contact with surface waters. Since the ductile shales are above these greywackes are much less permeable, making groundwater circulation towards the surface possible only in fracture zones. Zones with the contact between surface and mineralized ores are located in the Graça Hill and in the main meander of Ribeira de Oeiras, S of the Neves-Corvo Mine.

Through monitoring and surface water control, Fernandez-Rubio y Associados (1994), the hydrogeological system of Neves-Corvo identified three hydrogeological units:

- Upper Shallow System – This system is considered to be an aquifer or an aquitard, free to semi-confined, relatively heterogenous with permeability decreasing in depth, extends from surface to 100 to 200 meters depth.

- Intermediate system – Considered a semi-confined defined in the limit of the previous aquifer, until the top of the mineralization.
- Deep mining system – Confined aquifer composed by the mineralized deposits and overimposed rocks.

The chemical groundwater analysis has origin mostly from this deep mining system, since they often cross mineralized deposits. They were collected in the mine. However, they are considered as pristine groundwater.

5.2 Fluid composition, brines, meteoric waters

Regular analyses from two different groundwater surveys in the deep mining system of Neves-Corvo Mine have been conducted. Most of them are collected at a depth of ~600 meters. One of chosen the surveys was conducted in July 2017 and the other in April 2018 to compare. All the samples come from water from deep aquifer that crosses the ore. Most groundwaters have hydrogeological Na-Cl-HCO_3 or Na-Mg-SO_4 facies. Values reported here are maximum limit values. These values come from different groundwater sources as referred from its name and location and as far as possible, contain the important information for the project, as referred in Reikjavique meeting.

- Fluid composition (fO_2, CO_2, salinity NaCl eq.)
- Redox conditions (Eh or pKe)
- pH (acid or alcaline)
- T range (°C)
- Pressure (bar)
- Flowrate (L/s)
- Amount of oxidizing compound
- Concentration of suspended solids (mg/l)
- Salinity (mg/l)

Tables 1 and 3 are referred to measured *in situ* parameters in different groundwater sources, collected in Neves-Corvo Mine, in the Lombador mass in two surveys carried out in July 2017. Tables 2 and 4 are referred Major parameters in different groundwater sources from Neves-Corvo, in the Lombador mass in April 2018. For depths reaching the bottom of the mine at 1,000 m (m.a.s.l.), although there is not a regular survey programme, the fluid temperature ranges from 30

to 39 °C with dissolved solids dried at 105 °C ranging from 800 to 23,200 mg/L (confidential information).

Table 1 – *Main parameters in different groundwater sources from Neves-Corvo, in the Lombador mass in July 2017. ORP=Oxi-reduction potential, EC=Electrical Conductivity µS/cm, RES=resistivity (ohm.cm), Resist=Resistivity (ohm.m), TDS= Total Dissolved Solids (ppm), D.O.=Dissolved Oxygen (%).*

ID	Depth Z [m]	Temp. [°C]	pH campo	ORP [mV]	Eh (V)	EC [µS/cm]	RES [Ohm-cm]	Resist (ohm.m)	TDS [ppm]	Press. [psi]	D.O. [%]
PH116	625	36.89	5.4	12.7	0.2172	14780	68	0.91	7393	15.735	41
PH114	740	36.87	7.8	8.3	0.2128	18380	54	16.69	9193	15.926	51.1
PH109	740	36.69	6.56	-123	0.0815	5784	173	1.36	2892	15.914	21.9
PH103	625	36.14	7.5	85.1	0.2896	2582	387	17.15	1291	15.723	54.9
PH115	625	35.35	3.46	287.5	0.492	8865	113	3	4432	15.725	53.5
PH104	625	33.68	8.02	68.9	0.2734	4113	243	21.6	2057	15.721	53.9
PH106	740	32.47	7.94	11.5	0.216	3169	316	2.41	1585	15.929	49.4
PH107	740	32.22	6.83	0.5	0.205	19900	50	6.86	9954	15.926	42
PH102	410	29.45	8.37	117.6	0.3221	1497	668	10.02	748	15.336	51.8

Table 2 – Main parameters in different groundwater sources from Neves-Corvo, in the Lombador mass in July 2017.

ID	m Z De-pth	Cu mg/L <0,002 Copper	Fe mg/L <0,005 Iron	Pb mg/L <0,01 Lead	Li mg/L <0,002 Lithium	Mg mg/L <0,02 Magne sium	Mn mg/L <0,0005 Mangane se	Si mg/L <0,6 Silicon	Ag mg/L <0,005 Silver	Na mg/L <0,03 Sodium	Sr mg/L <0,001 Stronti um	Sn mg/L <0,01 Tin	W µg/L 1.0 Tung sten	U µg/L 0.10 Urani um	Zn mg/L <0,003 Zinc
PH116	625	0.02	1050	1.34	1.88	1880	129	7.89	0.05	1130	3.19	0.1	2	1.19	797
PH114	740	0.0083	1.39	0.01	3.02	264	1.16	8.1	0.005	3570	10.3	0.01	1.6	0.1	2.32
PH109	740	0.002	94.8	0.01	0.441	86.2	4.26	5.11	0.005	804	1.89	0.01	1	0.22	60.7
PH103	625	0.002	0.171	0.01	0.26	52.2	0.0137	8.11	0.005	413	1.8	0.01	1.7	0.1	0.0218
PH115	625	0.002	408	0.01	0.904	670	26.3	8.05	0.005	854	4	0.01	1	2.68	166
PH104	625	0.0041	0.125	0.01	0.522	67.6	0.0488	6.79	0.005	783	1.52	0.01	1.2	1.36	0.0348
PH106	740	0.002	0.318	0.01	0.298	98.5	0.111	8.08	0.005	460	2.79	0.01	3.3	0.12	0.0564
PH107	740	0.0203	1.63	0.01	2.96	2600	49.8	7.2	0.005	2390	8.94	0.01	3.2	0.15	46.4
PH102	410	0.002	0.0495	0.01	0.0585	54.6	0.00797	8.48	0.005	208	0.762	0.01	1.4	0.1	0.003

Table 3 – Main parameters in different groundwater sources from Neves-Corvo, in the Lombador mass in April 2018. ORP=Oxi-reduction potential , EC=Electrical Conductivity µS/cm , RES=resistivity ohm.cm , Resist=Resistivity ohm.m , TDS= Total Dissolved Solids ppm, D.O.=Dissolved Oxygen %.

ID	Depth Z (m)	Temp.[°C]	pH	ORP [mV]	Eh (V)	EC [µS/cm]	RES [Ohm-cm]	TDS [ppm]	Press. [psi]	D.O. [%]
PH122	625	39.16	7.29	2.0	0.2	2278	439	1139	15.646	7.5
PH115	625	35.76	3.30	198.4	0.4	8287	121	4144	15.653	58.0
PH103	625	35.41	7.23	47.8	0.3	2802	357	1401	15.636	47.9
PH116	625	33.21	5.71	14.4	0.2	13110	76	6555	15.658	33.3
PH114	740	32.58	6.71	-58.8	0.1	17100	58	8552	15.819	46.3
PH109-1	1000	31.93	6.07	11.1	0.2	11150	90	5576	15.807	32.0
PH107	740	31.92	6.37	-19.8	0.2	17940	56	8970	15.825	21.4
PH133	765	30.98	6.66	-20.0	0.2	8036	124	4018	15.789	26.5
PH137	381.7	30.90	7.92	-63.9	0.1	2280	439	1140	15.270	11.4
PH136	380.4	30.44	7.86	-25.6	0.2	3405	294	1703	15.276	57.1
PH102	410	30.17	6.93	-31.4	0.2	1762	568	881	15.301	49.2

Table 4 – Main parameters in different groundwater sources from Neves-Corvo, in the Lombador mass in April 2018.

ID	(m) Z De-pth	Cu mg/L 0.002 Copper	Fe mg/L 0.005 Iron_	Pb mg/L 0.01 Lead	Li mg/L 0.002 Lithium	Mg mg/L 0.02 Magne sium	Mn mg/L 0.0005 Mangane se	Ni mg/L 0.005 Nickel	Si mg/L 0.6 Silico n	Ag mg/L 0.005 Silver	Na mg/L 0.03 Sodiu m	Sr mg/L 0.001 Stron tium	Sn mg/L <0,01 Tin	U µg/L 0.10 Urani um	Zn mg/L <0,003 Zinc
PH122	375	0.002	0.0593	0.01	0.112	53.4	0.024	0.005	8.28	0.005	365	1.16	0.01	0.10	0.003
PH115	375	0.0297	264	0.022	0.792	578	24.8	0.159	8.19	0.005	894	3.81	0.01	0.11	0.003
PH103	375	0.0043	0.0124	0.01	0.323	93.7	0.849	0.0051	8.14	0.005	565	2.03	0.01	1.37	132
PH116	375	0.002	490	0.024	1.27	1390	59.6	0.375	8.55	0.005	1360	5.64	0.01	0.1	1.77
PH114	260	0.002	25.9	0.01	1.81	500	7.22	0.0336	7.69	0.005	2880	9.43	0.01	0.46	466
PH109-1		0.002	155	0.174	0.633	638	24.3	0.0784	7.92	0.005	1580	2.01	0.01	0.14	17.2
PH107	260	0.0705	42.8	0.01	2.02	1300	20.3	0.104	8.09	0.005	2790	8.53	0.01	0.34	191
PH133	235	1.04	0.224	0.01	0.982	230	3.39	0.0437	6.42	0.005	1390	5.42	0.01	0.18	40.6
PH137	618.3	0.002	0.0877	0.01	0.206	12.4	0.00687	0.005	6.4	0.005	429	0.284	0.01	0.51	13.6
PH136	619.6	0.002	0.141	0.01	0.339	43	0.0196	0.005	7.02	0.005	651	0.946	0.01	0.1	0.003
PH102	590	0.0025	0.0049	0.01	0.0559	94.5	2.37	0.0166	7.4	0.005	253	1.03	0.01	0.1	0.003

5.3 Temperatures in depth

This sub-chapter summarizes the sub-chapter 4.5. Temperatures in depth, in CHPM2030 D1.2.2. It deals in detail with all the parameters used to draw an estimated Heat Flow Density map for mainland Portugal, with special emphasis to southern Portugal. At the moment of this report its importance lies on the deep relation between temperatures in depth with mineralized orebodies. Although the Heat Flow Density (HFD) values for mainland Portugal vary from 40 mW/m^2 to 115 mW/m^2, as reported in CHPM2030 D1.2.2., with an average value of about 75 mW/m^2, HFD values for the Centro Iberian Zone (CIZ) (up north) of the Hesperic Massif range from 65 mW/m^2 to 80

mW/m². In the South Portuguese Zone (SPZ), with location of our zone of interest, however, regional HFD values reach about 90 mW/m². A map of HFD in Mainland Portugal as reported in http://geoportal.lneg.pt, is shown in Figure 20.

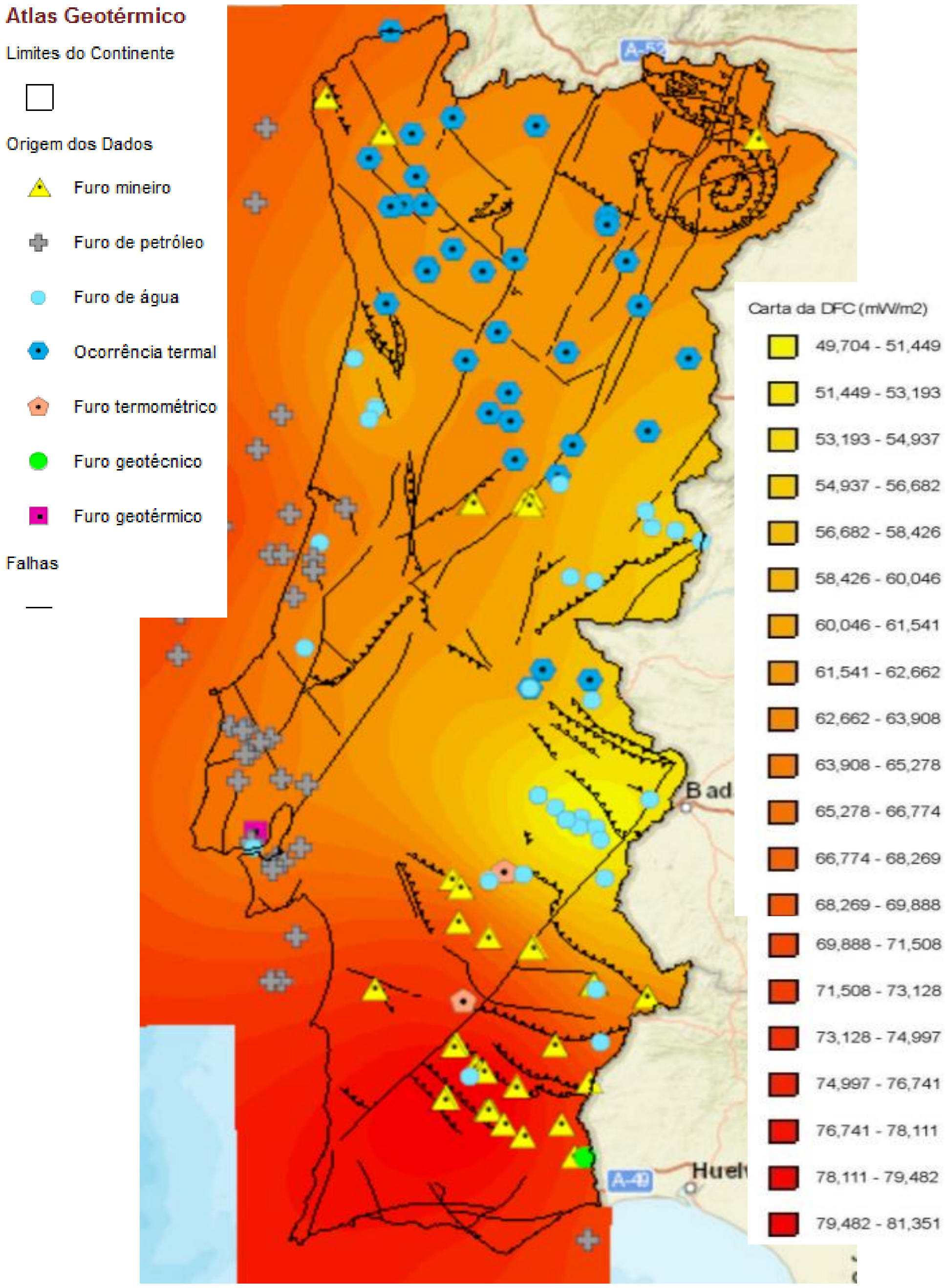

Figure 20. Heat flow map (DFC in Portuguese) for mainland Portugal, from the Portuguese Geothermal Atlas (Atlas Geoérmico) (http://geoportal.lneg.pt). Furo mineiro = mining well; furo de petróleo = oil well; furo de água = water well; ocorrência termal = thermal occurrence; furo termométrico = thermometric well; furo geotécnico =geotechnical well; furo geotérmico = geothermal well, falhas = faults). Units (mW/m²).

Figure 21shows the heat flow map for the Iberian Pyrite Belt (http://geoportal.lneg.pt). As seen there is an increase of the HFD regional values in the South Portuguese Zone, more specifically in the Neves-Corvo area.

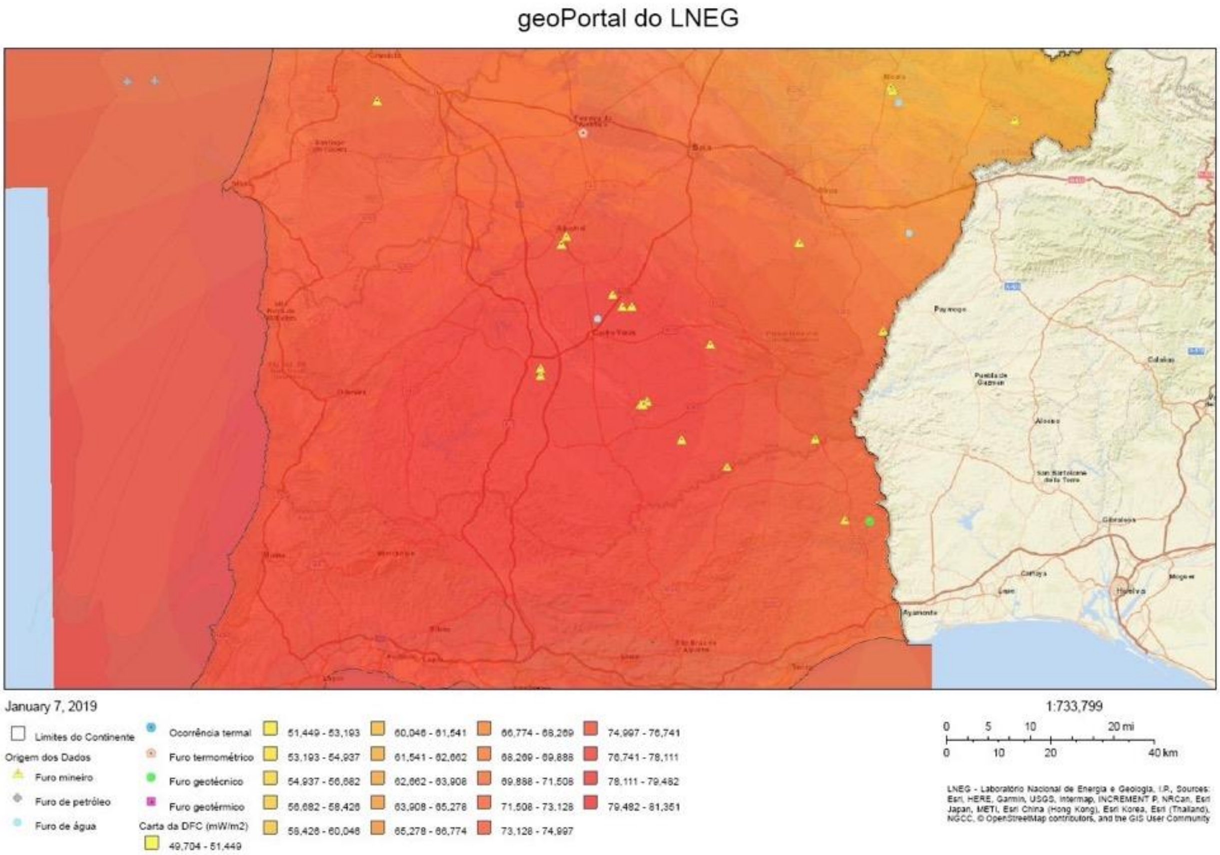

Figure 21. Surface Heat flow map (DFC in Portuguese) for the Iberian Pyrite Belt (http://geoportal.lneg.pt, from the Portuguese Geothermal Atlas (Atlas Geotérmico) (http://geoportal.lneg.pt). Furo mineiro = mining well; furo de petróleo = oil well); furo de água = water well; ocorrência termal = thermal occurrence; furo termométrico = thermometric well; furo geotécnico = geotechnical well; furo geotérmico = geothermal well, falhas = faults). Units (mW/m^2).

A map of the geothermal gradient for Mainland Portugal is shown in figure 22 and in the IPB is represented in figure 23 (http://geoportal.lneg.pt).

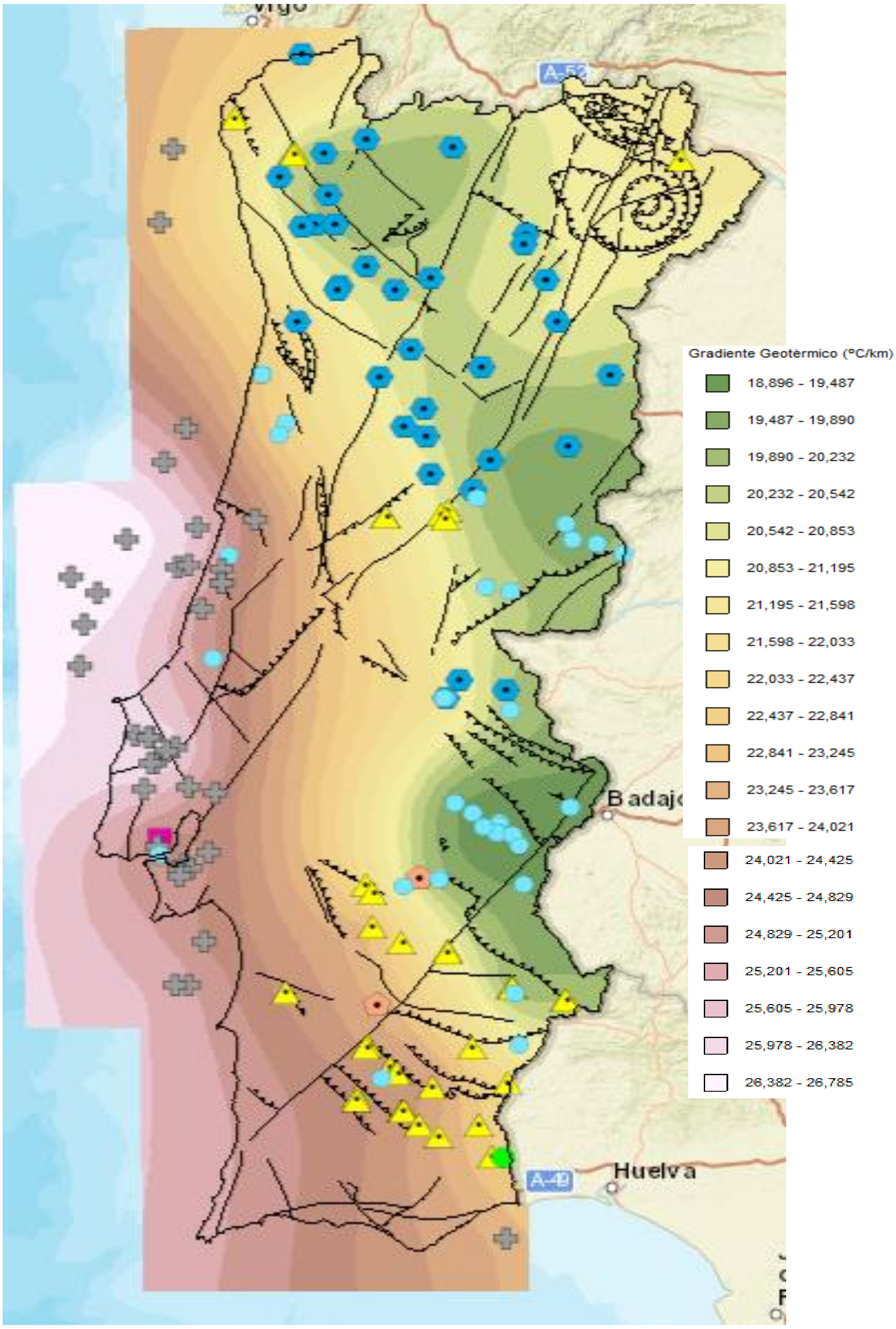

Figure 22. Geothermal gradient (Gradiente geotérmico in Portuguese) for Mainland Portugal with the IPB sector, [http://geoportal.lneg.pt,](http://geoportal.lneg.pt) from the Portuguese Geothermal Atlas (Atlas Getoérmico) (http://geoportal.lneg.pt). Furo mineiro = mining well; furo de petróleo = oil well); furo de água = water well; ocorrência termal = thermal occurrence; furo termométrico=thermometric well; furo geoténcico = geotechnical well; furo geotérmico = geothermal well, falhas = faults). Units °C/km.

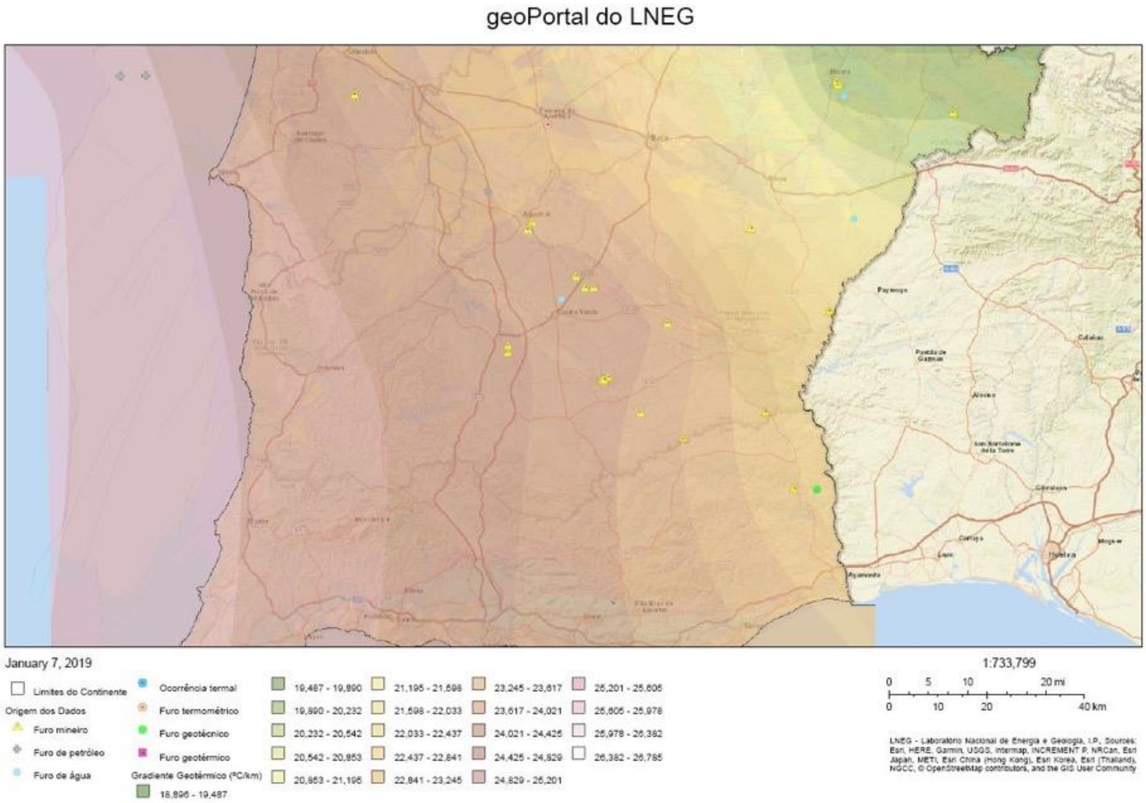

Figure 23. Geothermal gradient (Gradiente geotérmico in Portuguese) for the Iberian Pyrite Belt (http://geoportal.lneg.pt). from the Portuguese Geothermal Atlas (Atlas Getoérmico) (http://geoportal.lneg.pt). Furo mineiro=mining well; furo de petróleo=oil well); furo de água=water well; ocorrência termal=thermal occurrence; furo termométrico=thermometric well; furo geoténcico=geotechnical well; furo geotérmico=geothermal well, falhas=faults). Units °C/km.

As exhaustively reported in CHPM2030 D1.2.2, temperature in depth maps obtained with geothermal mapping together with thickness, transmissivity, and fluid chemical characteristics also in depth have a significant importance in the entire process to evaluate areas with more accurate methods and additional resources. Therefore, temperatures at 1,000, 2,000 and 5,000 m are estimated, following heat flow density estimations (from average thermal conductivity and geothermal gradient) and heat production values (A) (Haenel et al., 1980), based on spectrometric concentrations of U, Th and K, mostly from Rybach and Cermak (1982), Correia (1995) and aerospectrometric surveys for mining prospecting.

In this case, the step model was used.

$$T(z) - T_0 = \frac{q\,z}{k} + \frac{A\,z^2}{2\,k} \qquad (1)$$

where T(z) is the temperature at depth z (°C), T_0 is the average surface temperature on Earth (°C), z is the depth (m), A is the heat production per unit of volume ($Wm^{-1}K^{-1}$), q is the surface heat flow density (Wm^{-2}) and k is the thermal conductivity ($Wm^{-1}K^{-1}$)

Whenever possible, considered temperature was the measured temperature or interpolated between two measured temperatures, such as the case of onshore and offshore boreholes. In case of its inexistence, temperatures were extrapolated to bigger depths from shallower depths. The first was used only in several oil wells, after bottom bole temperatures correction for thermal disturbances caused by drilling (Haenel et al., 1988).

Heat Flow Density inferred from silica geothermometers (Ramalho and Correia, 2015) was not used for the IPB area, although its values were considered at national level, since there was information enough about k and A. Generally, temperatures in depth are higher in the Lusitanian Basin and in the SPZ, where the IPB is located.

Temperatures at 1000 m depth for the IPB are represented in http://www.geoportal.pt, in the Atlas de Geotérmico de Portugal Continental group of layers, reaching about 40 °C in the IPB, estimated with the methods described previously. According to Pacheco (2018, pers.com.) temperatures depth reach circa 40 °C in the lower levels of the Neves-Corvo Mine, about 900 m deep (CHPM2030 D1.2.2).

Temperatures at 2,000 m depth for the IPB are depicted in Figure 24, and can reach about 63 °C in the IPB. Estimated temperature in the area for 5,000 m deep, using the previously described methods for geothermal investigation is about 132 °C (Figure 25). EGS technology can therefore represent a huge renewable energy resource that could provide a significant base-load electric power if technical improvements in drilling technologies, rock fracturing techniques, and thermodynamic cycles were achieved

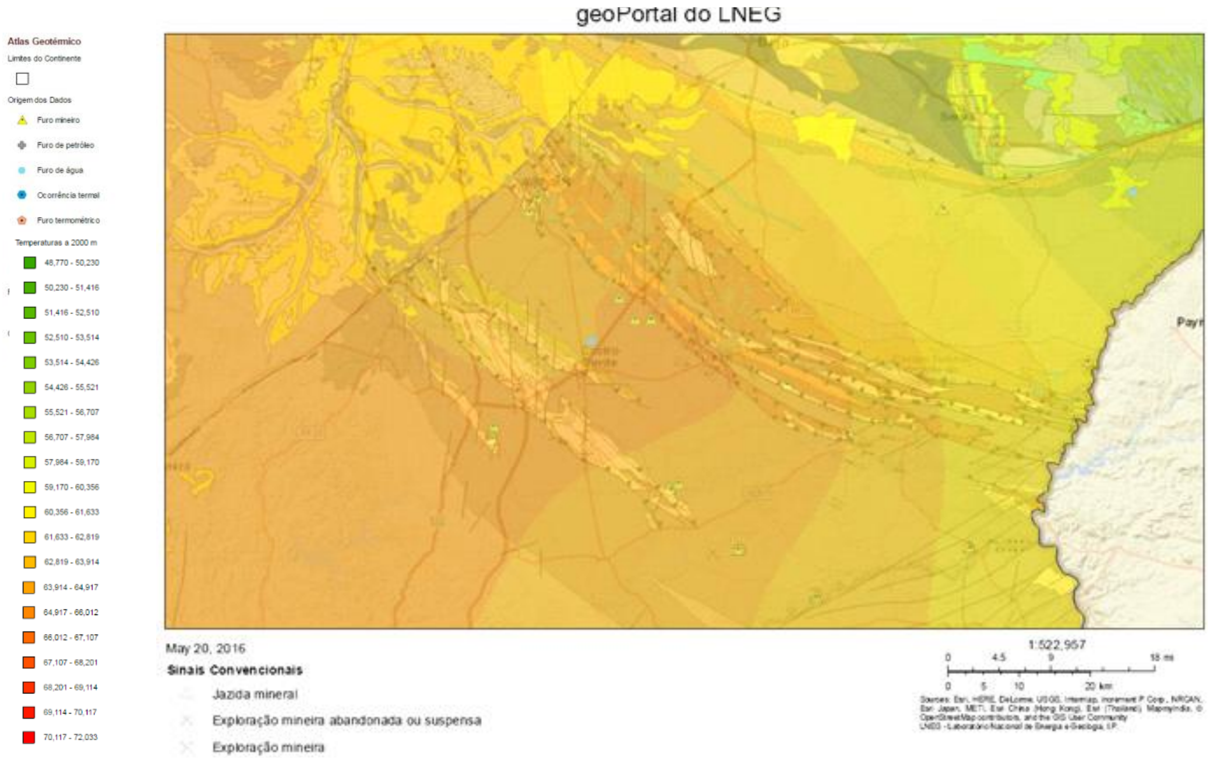

Figure 24. Temperature estimation (°C) at 2,000 m deep in the IPB Portuguese sector from the Portuguese Geothermal Atlas (Atlas Geotérmico) (http://geoportal.lneg.pt). Geology ad. from http://geoportal.lneg.pt. Furo mineiro = mining well; furo de petóleo = oil well); furo de água = water well; ocorrência termal = thermal occur rence; furo termométrico = thermometric well; jazida mineral = deposit ore; Exploração mineira abandonada ou suspense=abandoned or suspended mining exploitation; Exploração mineira = Mining exploitation).

Existing temperature in depth models and structural models in IPB will be jointly interpreted according with the 3D modelling that is being built.

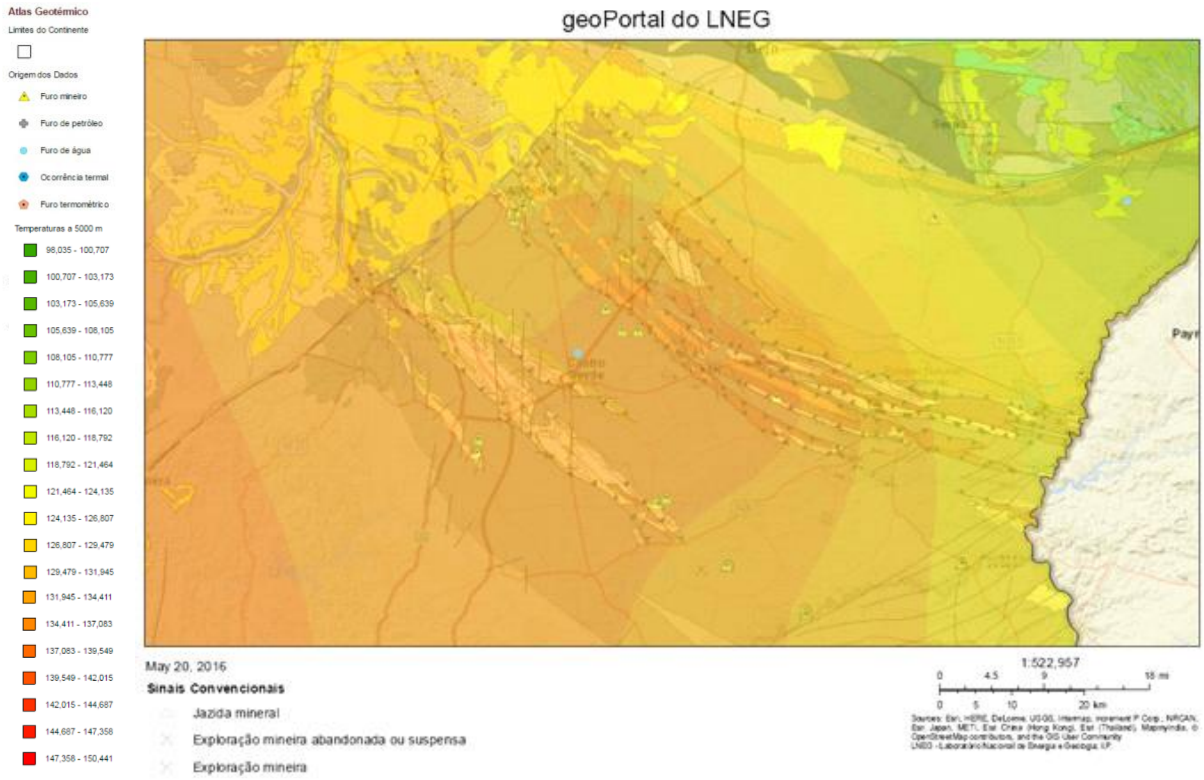

Figure 25. Temperature estimation (°C) at 5,000 m deep in the IPB Portuguese sector from the Portuguese Geothermal Atlas (Atlas Geotérmico) (http://geoportal.lneg.pt). Geology ad. from http://geoportal.lneg.pt. Furo mineiro=mining well; furo de petóleo=oil well); furo de água = water well; ocorrência termal = thermal occurrence; furo termométrico=thermometric well; jazida mineral = deposit ore; Exploração mineira abandonada ou suspense=abandoned or suspended mining exploitation; Exploração mineira = Mining exploitation).

6 INFORMATION FOR CHPM BUILDING BLOCKS

The following subchapters are focusing on the CHPM technological components and describes the available information regarding the study area. For future pilots, these aspects required to be fully described and elaborated. However, due to current knowledge gaps and limitations, actions and recommendations are going to be formulated to reach that level of understanding at the study area in the future. These next steps will be summaries in the Deliverable 6.3 Roadmap 2030 document.

6.1 Underground heat exchanger

Previous geothermal studies refer heat flow density values (HFD) of about 80 mW/m^2, in the area of Neves-Corvo Mine (Fig. 23). Although not the most attractive values for CHPM purposes, they are far from being disposable, and a well with 2500 meters depth may be enough for reaching the required temperatures for energy production.

6.2 Production/injection wells

At this moment, there are not available wells deep enough to ensure the duplet required by the method. Only if the new research data obtained through the Smart Exploration (H2020) and Explora (Alentejo2020) projects show good perspectives of the existence of a deeper orebody to exploit, deeper wells will be drilled by the mining company. The investment in these drill holes will be associated to the current VMS mineral exploration to be performed by Lundin Mining. Besides the presence of exploration drill holes conducted in the Neves-Corvo region up to 2,006 m length, that crossed mineralized stockwork at about 1,200-1,300 meters deep (Explora project, confidential information), so far, the deepest drill hole only achieve to a vertical depth of 1,645 m. However, at this particular depth the maximum reached temperature is of about 60 °C. Fig. 24 shows the temperature estimation (°C) at 2,000 m deep in the IPB Portuguese sector.

If recent reflection seismic surveys conducted at level -600 m of the mine and at the surface over the Lombador orebody provide good results concerning the prolongation of mineralization to deeper levels than the present one (-1,200 m), deeper wells will be drilled and therefore CHPM may be a feasible possibility to implement. So far, surface 1D loop transient electromagnetic (TEM) data suggests this possibility and, as stated above, stockwork mineralization has been intersected at 1200-1300m depth.

6.3 Metal recovery

Neves-Corvo extracts Cooper (Cu), Lead (Pb), Zinc (Zn) and Silver (Ag) only through an underground mine. Nowadays it produces about 45 000 tons of Cu and 75 000 tons of Zn per year. The deposits located within the Neves-Corvo Mining Concession consist of seven orebodies: Neves, Corvo, Graça, Zambujal, Lombador, Monte Branco and Semblana, the last two still in exploration phase, as referred in CHPM2030 D1.2.2 report. To date, a total of 1,037 surface drill holes for 822,266 m and a total of 5,928 underground drillholes for 591557m have been completed. The drilling, together with geophysical data has defined the seven mineralized zones of Neves, Corvo, Graça, Zambujal, Lombador, Monte Branco and Semblana with a combined total strike length of over 5,000 m and to depths of up to 1400m from surface (https:\\www.lundinmining.com).

6.4 Power plant

Neves-Corvo is located about 15 km away from Almodôvar and about 20 km southeast of the town of Castro Verde (Fig. 26) and approximately 220 km southeast of Lisbon. Almodôvar and Castro

Verde have about the same amount of population, with about 7,500 inhabitants in the county. The small town of Aljustrel, presently with IPB active mining (Almina company) and located slightly further away (42 km) has a population of around 9,200. Neves-Corvo has good connections to the national road network and a dedicated railway link into the Portuguese railway network and to the port of Setúbal (actual ore concentrate export area). There are no major centres of population close to the mine, although there are many small villages with populations numbered in the hundreds in the vicinities of the Neves Corvo Mine, many of them with inhabitants working in the mine. Energy may be used to supply these villages and the surface Mine facilities. The mine is connected to the national grid by a single 150 kV, 50 MVA rated, overhead power line 22.5 km long. The Neves-Corvo Mining Concession provides sufficient surface rights to accommodate the existing mine infrastructure and allow expansion as contemplated by ZEP.

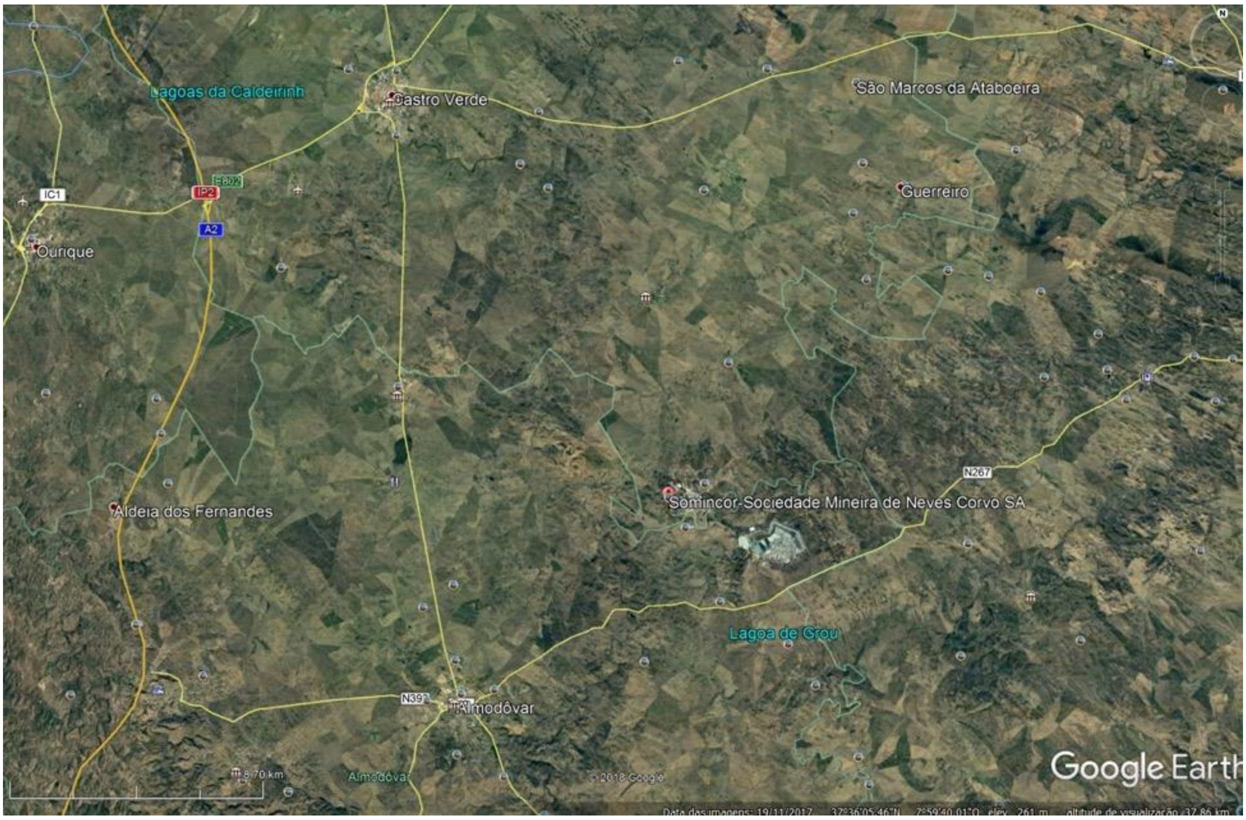

Figure 26. Location of Mina de Neves-Corvo and both major villages nearby, Almodôvar and Castro Verde (GoogleEarth@).

6.5 Salt Geothermal Power Generation

Although Neves-Corvo does not have deep enough drill holes to extract geothermal brine, there is a stream nearby named Ribeira de Oeiras, containing freshwater above the mine. The Oeiras stream valley cross cut several vertical faults taking water towards depth. In the mining area the stream floor is cemented to avoid and control water infiltration in the area where are located the

mining infrastructures (shafts and galleries). As common in the south of Portugal the water flow is very low and seasonal (long dry season). Considering the landscape and geological settings it cannot be considered as an option for salt geothermal power generation.

Fresh water is supplied to the mine via a 400 mm diameter pipeline from the Santa Clara reservoir, approximately 40 km west of the mine. Supply capacity is 600 m^3/h whilst storage facilities close to the mine hold 30 days' requirements. The current total fresh water requirement for the mine and plant is approximately 180m^3/h with as much as 75 % of the volume being reused (www.lundinmining.com).

6.6 Environmental, social, political background

Portugal, like many other countries is facing the challenge of changing the energy paradigm. Renewable energies, especially geothermal energy, play an important role in this subject since its use is not limited in time and is available 24/7. Geothermal energy being ecological, with reduced gas emissions towards the atmosphere, safe and easy to control has also the possibility of being jointly used with other energy sources to increase its efficiency.

This type of energy is economically sustainable although there is a significant initial investment, either for small or medium size installations.

Able of being used at regional level is therefore an increasing factor of industrial competitively, bringing positive effects in the economy development and job creation.

However, these types of energies have a weak dissemination in public opinion and there is a total absence of tradition in this type of geothermal exploitations, in opposition of their strong dissemination in northern Europe. Nevertheless, the fact that Portugal has had so far no commercial oil-discovery and several public contestation and protest against oil exploration in Portuguese mainland and offshore, opens the ways to alternative energy sources, such as geothermal exploration.

In spite of this, legislation in Portugal is still very low focused. Indeed, there is a lack of legislation adapted to the new reality of shallow geothermal installations. Geothermal resources are generally ruled by the Portuguese Law 15/2015 of June 22nd and the Decree-Law 87/90, from March 16th. Having a mixed technical component in the Geology and Energy areas, there are not many companies with skills to ensure the quality of these projects and to implement this type of energy. Synergies must be assured if this type of technology will ever be implemented.

Specifically, in the Mine of Neves-Corvo SOMINCOR has developed a corporate and site strategy for reducing energy use and GHG are monitored and reported as part of the Air Quality Greenhouse Gas Management Plan (“AQGHGMP”), although this system has only recently been put in place. To meet water quality discharge thresholds, the water management system has been recently redesigned and reengineered. Portuguese discharge quality standards have been met since the introduction of these new systems. Overall water consumption and discharge into surface water bodies is expected to increase as a result of the Zinc Expansion Project (ZEP), but will stay well within the permitted requirements due to improvements in water recycling and water management on site.

6.7 Financial

At this moment the Portuguese government does not contribute continuously to private initiatives regarding the implementation and use of any renewable energy or any innovative projects regarding the paradigm of energy transition. Special calls with special objectives are therefore at the moment launched in a non-periodical way. Anyway, the Fundo de Apoio à Inovação (FAI) (http://fai.pt/) is one of the national governmental organizations that can provide some financial aid to the implementation of new concepts of generating heat in a renewable and clean way.

6.8 Meeting stakeholder requirements

The Pilot mission objective at the Portuguese Iberian Pyrite Belt, Task 6.2.2, was twofold, serving the overall objective of setting the ground for subsequent pilot implementation. The first, and main goal was developing the evaluation template and investigating the Portuguese Iberian Pyrite Belt according to it. The result of this subtask is this report. The second objective was to develop a surveying program covering simultaneously stakeholder requirements from the mining and geothermal sectors, eventually combining the two agendas under the same program. This summary describes the beginning of this effort.

So far, the knowledge about the existence of deep orebodies is restrained to about 1500 m depth. Since mineral exploration is the major activity that brings local and national economy into life, only if new deeper orebodies will be found under the scope of mineral exploration may bring the two agendas (mineral and geothermal) together. Keeping in mind that working together on mineral exploration and on geothermal exploration, a CHPM exploration campaign or a complex survey for CHPM, would be dependent on new deeper orebodies discoveries and the evolution of technical capabilities for exploitation at such large depths. The combination of the tools and approaches

from mineral and geothermal exploration will therefore be a target to reach if that scenario will become a reality. If so, a CHPM pilot technology involving the mine can be included in the roadmapping for 2030, if the Portuguese Government and Lundin Mining will accept to sign a Grant Agreement that involves mineral and geothermal stakeholder requirements for geo-data acquisition.

This subtask will be further explained in the Deliverable 6.3 Roadmap document, and will provide future recommendation on this line of activities.

7. 3D MODELLING

This 3D modelling chapter was deliberately left for last because it contains the information that will be used in first stages of Roadmapping. In fact, due to unfinished character of this subject, it is an important part of the Roadmapping. So far, Oasis Montaj and GoCad are being used to build a 3D model of the joint geological, geophysical and mining information gathered in Neves-Corvo Mine concession area. Besides the drillholes data, superficial geological mapping and underground mining data were considered in the generation of key surfaces related with the major geological units. These data are crucial to constrains the geological and geophysical models and to infer the existence of deeper mineral orebodies that can be useful for CHPM purposes. Special focus is on the Lombador orebody, that shows good prospects of continuity at depth. This orebody that may serve simultaneously the goals of the ultra-deep mining activity and temperatures in depth high enough to produce energy (http://geoportal.lneg.pt). Therefore, taking as basis the Promine project "Nano-particle products from new mineral resources in Europe" (https://cordis.europa.eu/project/rcn/93327/reporting/en), further developments were undertaken and included as information to develop in CHPM technology. Some non-crucial, but confidential, selected 3D models were introduced in this report so that a quick look at the models can be foreseen as the possible prolongation in depth of the Lombador orebody. Figures 27 and 28 show the 3D model of the Neves-Corvo mine region depicting major stratigraphic boundaries, orebodies and location of drillholes.

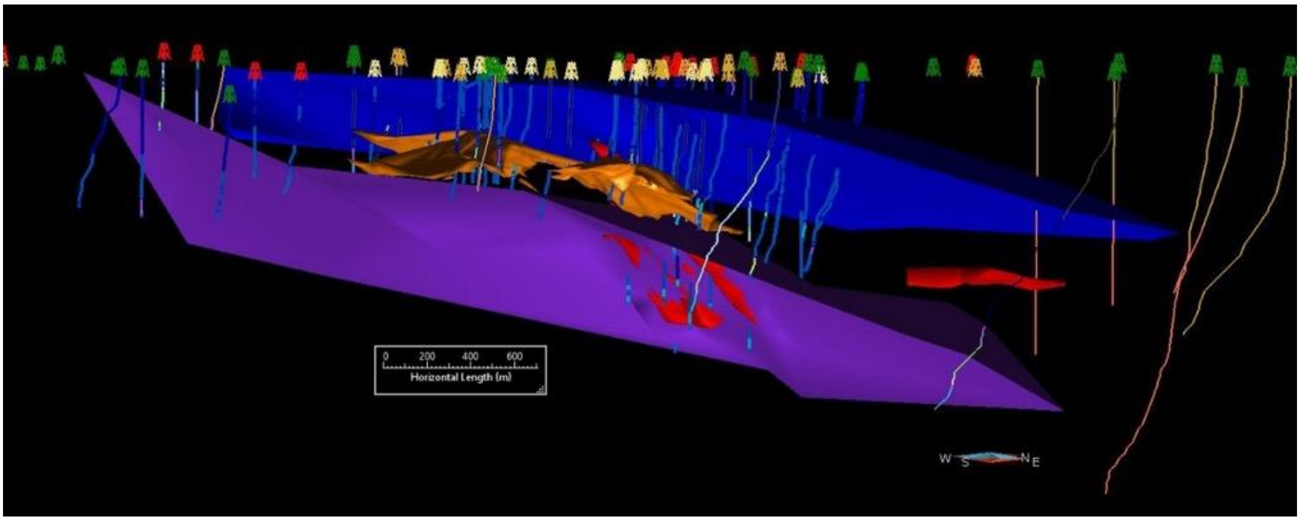

Figure 27. 3D model of the Neves-Corvo mine region showing major stratigraphic boundaries, orebodies and location of drillholes in GoCad. Legend: Blue - Top of ore-bearing Volcanic-Sedimentary Complex (VSC) geol ogical unit. Purple - top of the basement unit Phyllite - Quartzite (PQ) Formation. Red - Semblana and Lombador orebodies. Orange - Neves, Corvo and Graça orebodies. Drillholes are plotted in different colours because they belong to different surveys. White boreholes have no information.

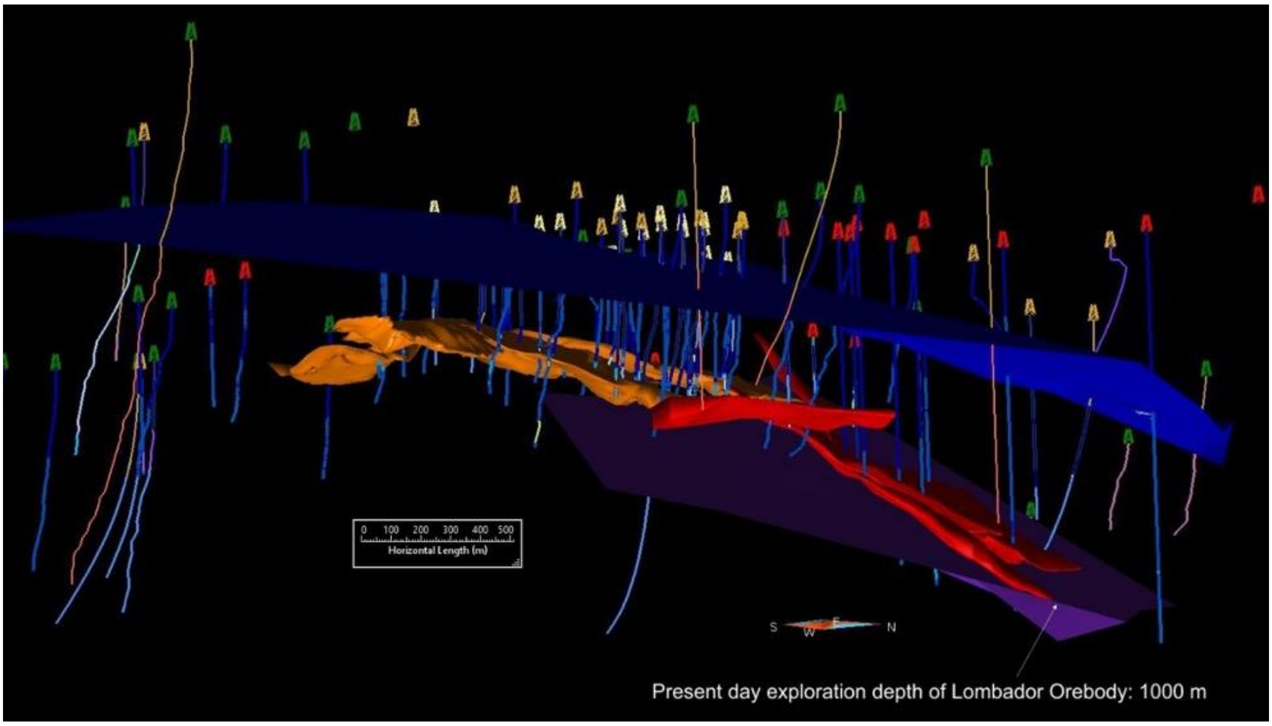

Figure 28: A different view of the 3D model of the Neves-Corvo mine region showing major stratigraphic boundaries, orebodies and location of drillholes in GoCad. Legend: Blue - Top of ore-bearing Volcanic-Sedimentary Complex (VSC) geological unit. Purple - top of the basement unit Phyllite-Quartzite Formation. Red - Semblana and Lombador orebodies. Orange - Neves, Corvo and Graça orebodies. Drillholes are plotted in different colours because they belong to different surveys. White boreholes have no information.

The Lombador strikes in depth, but it was crossed by very few drillholes at the time of the Promine project. Figure 30 shows a close-up view of the 3D model and recent drill holes showing present exploitation depth of the Lombador orebody.

The inclusion of transient electro-magnetic (TEM) cross-section resulting from the inversion of 1D surface loops, overlapped to the 3D geological model shows the prolongation of the Lombador orebody host rocks till at least 1600 m, as suggested by TEM data and confirmed by a drillhole (in Figure 31). The existence of 3 loops with 3 lines inside of it, with 3000 meters long and 23 cross sections as the inversion of 1D surface loops to be processed with Maxwell, will allow a much more detailed view of the Lombador orebody, based on its electromagnetic characteristics.

The result of the inverted 1D surface loop, chosen by crossing the recent borehole shown in Fig. 29, clearly shows a distinctive layer with higher electrical conductivities that may correspond the prolonging in depth of Lombador orebody. The same Figure 30 shows an area where a borehole, drilled from the mine gallery at 600 meters depth intercepted a stockwork mineralization at 1400-1500 meters depth, a suggested by the figure. This leaves good prospects to the 3D modelling that will be carried out in the TEM inverted sections, to build the 3D model, including the recently acquired reflection seismics in the mine.

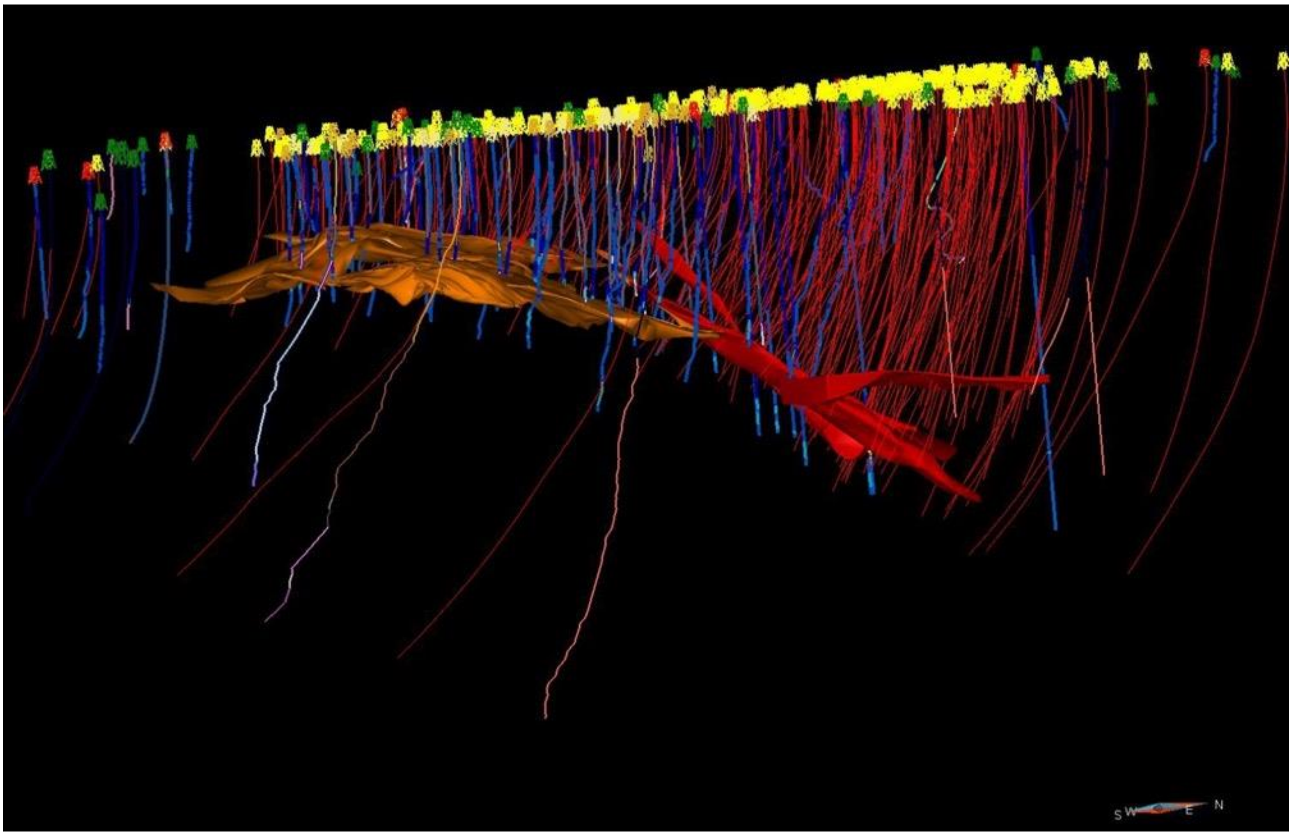

Figure 29. Close-up view in a different perpective of the 3D GoCad model showing present exploitation depth of the Lombador orebody. Legend: Red - Semblana and Lombador orebodies. Orange - Neves, Corvo and Graça orebodies. Yellow corresponds to new drillhole data drilled after Promine project. Notice deep drillholes cutting across Lombador orebody and going much deeper. Drillholes are plotted in different colours because they belong to different surveys.

Reprocessing 2D seismic profiles overlapped to the 3D geological model are part of the Smart Exploration project (Fig. 31). The prolongation of the Lombador orebody host rocks till at least 1600 m is also suggested by 2D seismic data conducted by Promine.

The mine galleries intersecting the Neves-Corvo and Lombador orebodies are depicted in Fig. 32. In this figure, purple parts correspond to location of receivers that were used to collect the in-mine recent seismic data, at the level 640 m. The purpose was to investigate how deep mineralization extends down dip.

As it can also be seen from Fig. 32, there are good prospects that the Lombador orebody extends in depth, but only with the data processing that will be carried out by Smart Exploration and Explora projects, further information can be added to CHPM purposes.

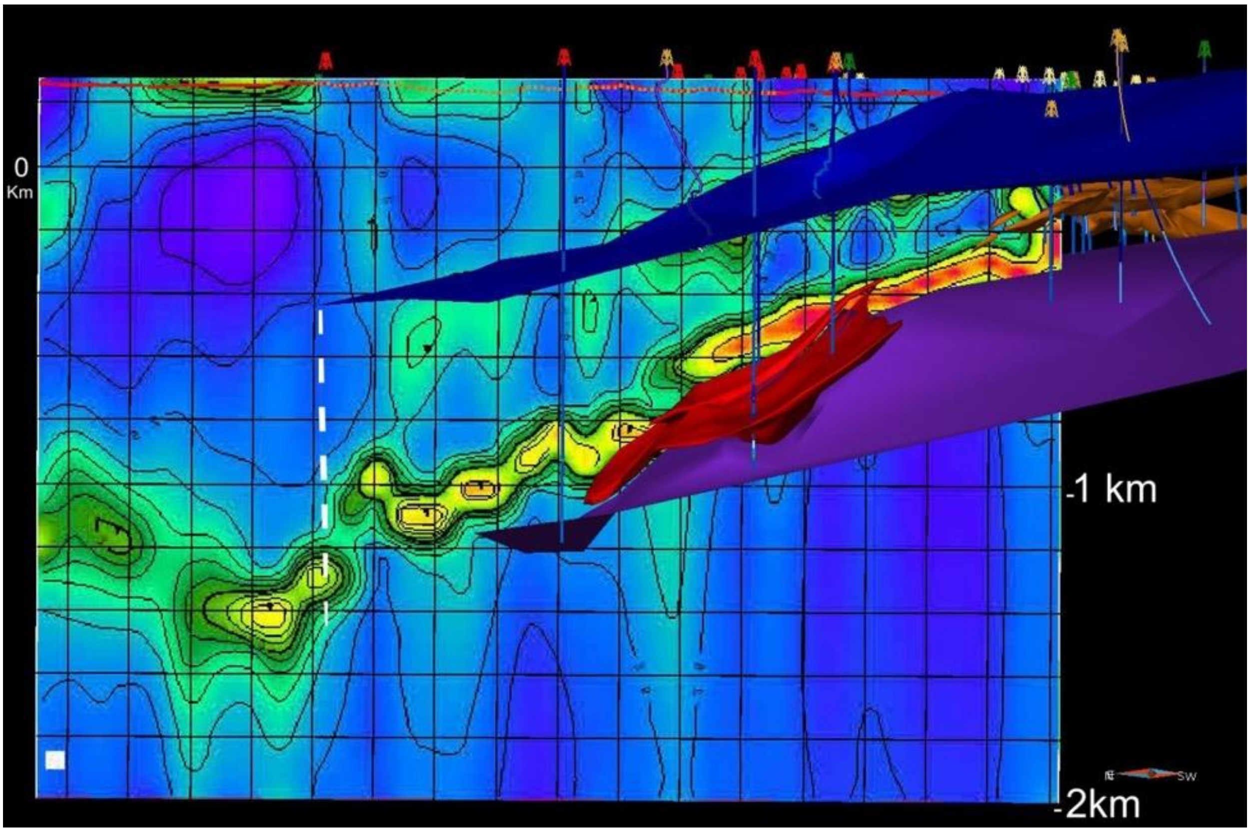

Figure 30. Transient electro-magnetic (TEM) cross-section resulting from the inversion of 1D surface loops, overlapped to the 3D geological model. Legend: Blue - Top of ore-bearing Volcanic-Sedimentary Complex (VSC) geological unit. Purple - top of the basement unit Phyllite-Quartzite Formation. Red - Semblana and Lombador orebodies. Orange - Neves, Corvo and Graça orebodies. The prolongation of the Lombador orebody host rocks till at least 1600 m is suggested by TEM data. Dash white line represent approximate location of recent borehole that intersected stockwork mineralization at 1400-1500 m depth. Blue corresponds to low electrical electrical conductivities, yellow and finally red correspond to high and very high electrical conductivities. Drillholes are plotted in different colours because they belong to different surveys.

8 CONCLUDING REMARKS

The last edition of the "Geothermal Resources Atlas of Europe" (Hurter and Haenel, 2002), incorporates this dataset and added some thermometric boreholes drilled with specific geothermal purposes near the IPB. According with Heat Flow Density Commission the geothermal information approach is reliable and quality of data is improved as more information is acquired. The geothermal database followed the format described in Ramalho (1999) and follows as much as possible the standards defined by the International Heat Flow Commission (Jessop, 1990). For the reached studied depths (~1,000 m) the temperatures (~40°C) cannot allow questioning the implementation of a CHPM facility. But at 2,000 m depth, estimated temperature of about 70 °C, may be interesting for the implementation of this technique. The existence in depth of further

orebodies yet to be exploited may be considered as promising and therefor, with a good potential for the use of CHPM.

Nevertheless, Southern Portugal may show good prospects to implement CHPM technology. However, it still lacks the co-existence of deep wells, able of producing energy and the absolute knowledge of ultra-deep orebodies that supply brines with adequate characteristics.

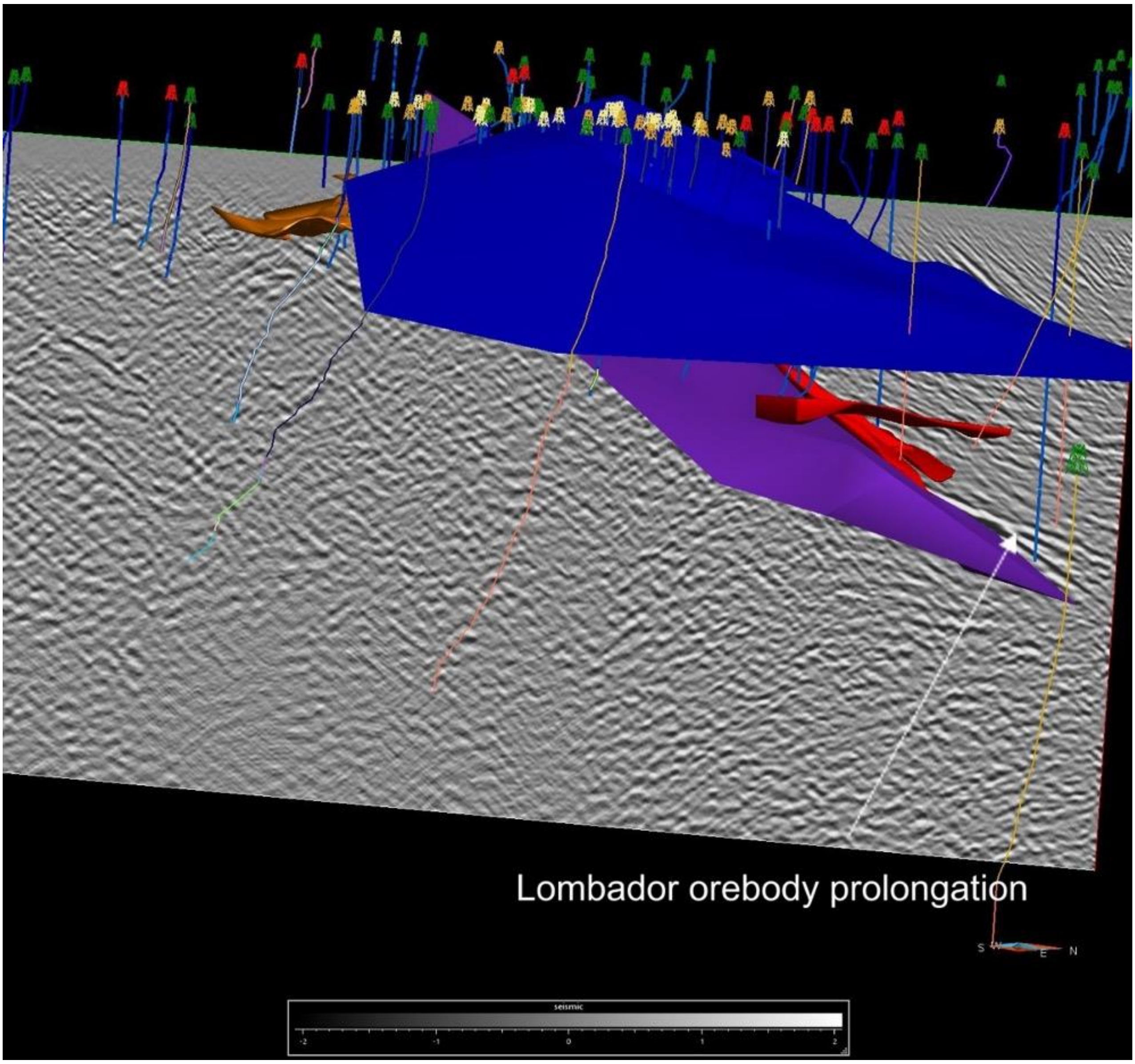

Figure 31. Reprocessed 2D seismic profile overlapped to the 3D geological model. Legend: Blue - Top of ore-bearing Volcanic-Sedimentary Complex (VSC) geological unit. Purple - top of the basement unit Phyllite-Quartzite Formation. Red - Semblana and Lombador orebodies. Orange - Neves, Corvo and Graça orebodies. The prolongation of the Lombador orebody host rocks till at least 1600 m is suggested by seismic data. Drillholes are plotted in different colours because they belong to different surveys.

So far, the deepest well drilled by Neves-Corvo reaches about 2 km and maximum temperature is about 65 °C. This leaves us with a big gap between the necessary depths for CHPM technology and the dataset which is currently available.

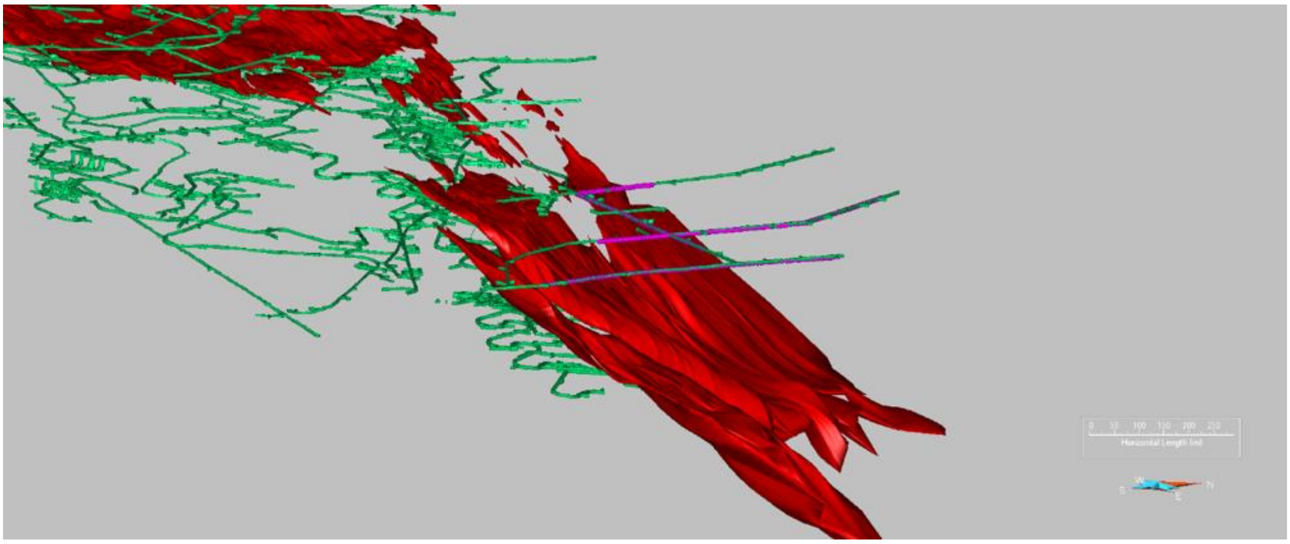

Figure 32. Mine galleries intersecting the Neves-Corvo and Lombador orebodies (green). Purple parts correspond to location of receivers that were used to collect in-mine seismic data, at the level 640 m. The purpose was to investigate how deep mineralization extends down dip..

Very recent geophysical and drilling results suggest the possibility of the existence of mineralization at least at 1.5 km, possibly at bigger depths, decreasing the gap between present mineralization and CHPM required depths.

Although 3D modelling of the orebodies is still underway. The studied data also allow to consider the future development of EGS facilities. The Roadmapping for 2030 document will aim to highlight some important issues to implement in such a time horizon CHPM.

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