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Magnetotelluric investigation of the Iberian lithosphere and asthenosphere beneath Tajo Basin and Betic Cordillera (PICASSO - Phase I)

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SUMMARY

The PICASSO project intends to enhance knowledge about the geological setting of the Alboran Domain beneath the western Mediterranean Sea and its surrounding regions, Northern Africa and Iberian Peninsula, and through that knowledge to understand processes related to continent-continent collision. The Iberian Peninsula is the focus of the first phase of DIAS's PICASSO efforts, and comprises a magnetotelluric profile crossing the Tajo Basin and Betics Cordillera. The overarching goal of this phase is to reveal deep-seated features previously undetected due to the location of the Peninsula on the edge of Europe and the associated complication in deep-probing seismic tomography studies, along with the circumstance that prior MT studies were mainly focussed on regions of alpine orogeny.

Low solar activity combined with a high level of local anthropogenic noise reduced the data quality and required exceedingly careful time series processing. Subsequent analyses of the responses revealed varying geoelectric strike direction with depth and laterally along profile. This consequently resulted in separate inversions for the Betics region, and for crustal and mantle structures of the Tajo Basin. Preliminary inversion results of the Tajo Basin subsurface indicate a relatively conducting upper crust underlain by more resistive structures in the lower crust and mantle, whereby most noticeable features of the model are the apparent upwelling of a resistive lower crustal layer beneath the centre of the basin and the presence of an upper crustal resistor in its northern half.

Keywords: Magnetotellurics, Lithosphere, Asthenosphere, Iberia, PICASSO

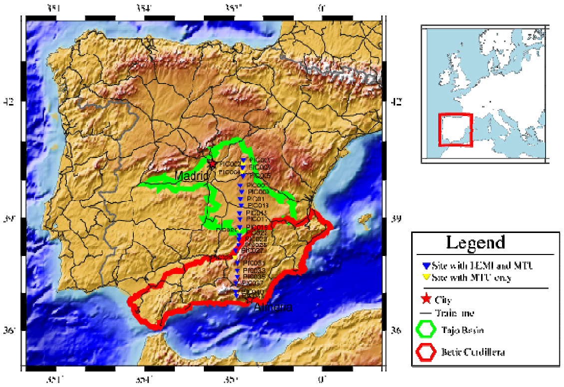

Figure 1. Location of the area under investigation, MT stations are indicated by inverted triangles, black lines denote DC railway lines which are sources of electromagnetic noise.

INTRODUCTION

PICASSO (Program to Investigate Convective Alboran Sea System Overturn) is an international, multi-disciplinary project with the overarching objective to improve knowledge of internal structure and plate-tectonic processes in the highly complex three-dimensional region formed by the collision of the African and European plates under the effect of the Mediterranean plate motion. The first phase of the DIAS magnetotelluric (MT) component of the PICASSO project was carried out in Southern Spain from September-November2007 along a profile from the outskirts of Madrid across the central Spain plateau to the Mediterranean Sea through the Betic Mountain Chain (Fig. 1). The profile focuses on the investigation of subsurface structures beneath the Tajo Basin (central Spain) and the Betic Mountain Chain (southern border of Spain).

Uppermost mantle structures beneath Iberia are not well known since seismic tomography studies, which besides MT, have the best potential to reveal deep-seated features, are complicated due to the regions location on the edge of Europe and the associated problems with the installation and maintaining of long term stations in the Atlantic Ocean. Owing to the tectonic history of Spain, previous deep-probing geophysical studies, MT in particular, were focused on the northern and southern boundaries of Iberia, i.e. the Pyrenees and the Betic Cordillera. Their aims were to examine geological processes taking place during the Alpine orogeny, whereas central Spain was mainly the subject of near-surface research. As a result, central Spain has remained comparatively neglected in terms of deep-probing investigations. The investigation of the lithosphere–asthenosphere boundary (LAB) beneath the central Iberian region, which would enhance knowledge about the present subsurface structures and preceding tectonic evolution, is among others, one of the aims of our work.

GEOLOGICAL SETTING

The Tajo Basin

The Tajo Basin, located in central Spain (Fig. 1), was formed as part of the Iberian Basin during Middle Triassic times and, after subsequent deformation during Late Triassic to Jurassic times, separated from the northern regions (forming the Ebro and Duero Basins). This separation was due to the uplift of the Iberian and Catalonian Coastal Ranges during Palaeogene Alpine convergence between Europe and Africa. Later the basin became the focus of Tertiary sedimentation, establishing it as an intracratonic depocentre and underwent little or no alpine deformation. It became thereafter subdivided due to the Pliocene uplift of the Altomira Range, a branch of the Iberian Range, into the Madrid Basin and the much smaller Loranca Basin (also referred to as Intermediate Depression or western sector of the Jucar Basin) in the north, and the Manchega Plain in the south.

From previous geophysical studies the subsurface below the Tajo Basin can be inferred to be comprise three crustal layers, reaching down to depths of around 10, 24, and 31 km respectively, and a lithosphere-asthenosphere boundary (LAB) at a depth between 110 and 130 km. The upper crustal layer is assumed to be formed from metamorphic rocks, whereas the middle and lower crust consist of felsic intrusives and granulites respectively. In the eastern part of the Tajo Basin, including the Loranca Basin and parts of the Manchega Plain, the Neogene sediments are likely to be located over Mesozoic rocks forming the Iberian Range and the Campo de Montiel, north-west and south of the basin. These are potentially partly underlain by Variscan rocks of the Iberian Massif in the region of the Manchega Plain and the Campo de Montiel as suggested by ambient noise tomography.

Geological interfaces below the Tajo Basin, as inferred from seismic studies, coincide with the borders of the Betic Cordillera (south of the basin) and the Iberian Range region (north-east of the basin). They possess a NW-SE and ENE-WSW orientation respectively, thus indicating a different geologic strike direction for the northern and southern part of our profile. Furthermore since the anomaly associated with the Iberian Range cannot be observed at depths greater than 53 km, whereas the low velocity feature occurring slightly north of the Betics Cordillera reaches down to at least 200 km, it is likely that the geoelectric strike direction below our profile will also change with depth.

DATA ANALYSIS

Data acquisition

Between October and November 2007 magnetotelluric (MT) data were acquired along a 400-km-long, approximately north-south orientated profile from a region around 100 km east of Madrid to the city of Almeria at the Mediterranean Sea, crossing the Tajo Basin and the Betic Cordillera (Fig. 1). The location of the profile was chosen to avoid sources of electromagnetic noise, such as highly populated areas, severe topography, DC electric train network and anthropogenic conditions.

Data were successfully recorded at 20 locations using Phoenix Geophysics broadband MTU stations and Lviv long-period LEMI stations, with station spacing close to 20 km; 4 additional Phoenix Geophysics broadband MTU station were installed at certain areas along the profile reducing the station spacing to 10 km in order to increase resolution in these regions.

Data processing

The acquired time series data at longer periods generally suffer from low signal-to-noise ratio due to the extremely low solar activity throughout the recording period (the lowest since the Maunder Minimum between 1645 and 1715), in combination with the high degree of local anthropogenic EM noise owing to the dense population of Spain and the well-developed DC electric railway network. Thus, careful data processing was performed using the **EMTF** algorithm by Egbert [1997] for broadband MT data and a robust processing program, developed by Smirnov [2003], for the long-period data. After additional removal of corrupted segments in the responses, most likely due to DC train lines noise, geoelectric strike direction was determined by the aid of the **strike** program [McNeice & Jones, 2001]. Different regimes of geoelectric strike behaviour are identified along the profile and with depth, revealing a highly 3D structure beneath the Betics, an approximately NW-SE direction for the crust beneath the Tajo Basin and an approximately NE-SW direction of the upper mantle.

Data inversion

Due to the diverse directions in geoelectric strike the data are divided into subsets and inverted separately using the routines developed by Randy Mackie, which are part of the **WinGLink** software package [Geosystems, 2004]. Due to the limited ability of the utilised inversion software to resolve structures in a highly 3D subsurface, current investigation is focussed on the region of the Tajo Basin. Initially, parameters for the smooth inversion are determined in a *most-squares* sense, identifying combinations that result in an RMS-misfit of 2 or below (Fig. 2). From these models, and results of prior seismic investigations, a 1D conductivity-depth distribution averaged along our profile is constructed which is used as a starting model for subsequent inversion (Fig. 3). Inversion models exhibit structures with increased conductivity in the upper crust and a relatively more resistive intermediate and lower crust over a moderately resistive mantle. The basin exhibits a fairly 1D behaviour; noticeable features of our inversion model are an upwelling of the lower crustal layer in the centre of the basin and a resistive structure in the upper crust of its northern half (Fig. 4).

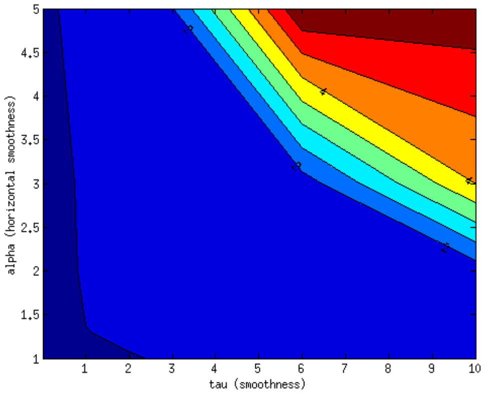

Figure 2. Gridded RMS-misfit of smooth inversions with different combinations of smoothing parameters.

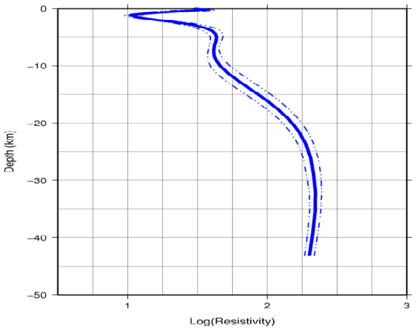

Figure 3. 1D conductivity depth distribution averaged along our profile, used as a starting model for subsequent inversion; the solid line displays the averaged values whereas the variance is indicated by the dotted line.

CONCLUSIONS

Our investigation aims on enhancing the information about the geological setting of the Iberian Peninsula with focus on conductivity distribution beneath central Spain and the Betics region.

Key statements of our study are at present

- Data quality is seriously affected by the signal-to-noise ratio during the recording time
- Geoelectric strike direction varies with depth and along the profile
- The 3D subsurface of the Betics Cordillera impedes the investigation there
- Our MT investigation provides new details about deep-seated structures beneath the Tajo Basin
- A conducting upper crust over more resistive lower crust and mantle structures is indicated by inversion models for the Tajo Basin with an observed upwelling of the lower mantle in the centre of the basin and a resistive feature in the upper crust.

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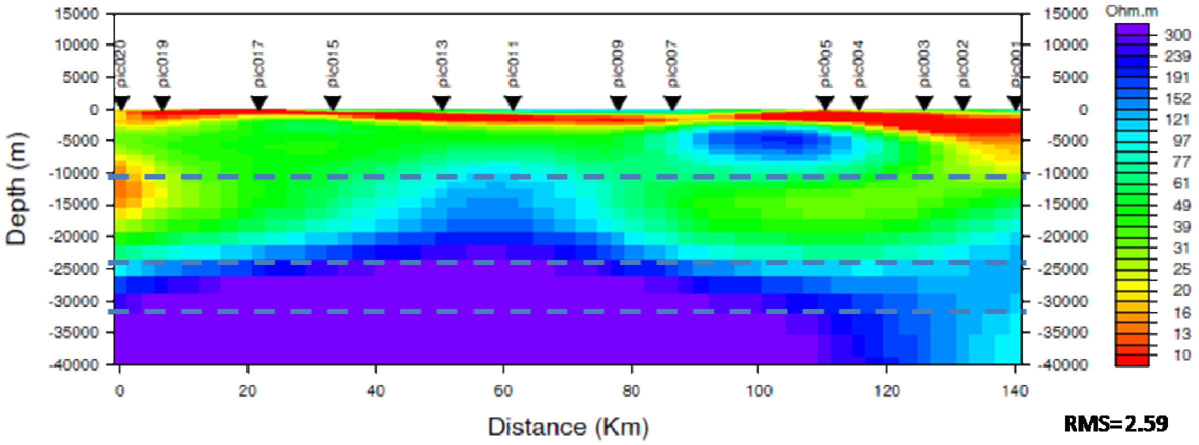

Figure 4. Inversion model of the magnetotelluric data acquired in the Tajo Basin, revealing a conductive layer in the upper crust underlain by a moderately conductive intermediate and lower crust and a relatively resistive lower mantle; dotted lines indicate the depth of the different layers as determined by seismic reflection and refraction data. Most noticeable features of the model are (a) the apparent upwelling of the lower crustal layer beneath stations pic009 – pic011 (b) and the upper crustal resistor below stations pic004 – pic007.