PICASSO- Phase I: MT Investigation of the Betic-Rif mountain system. Comparison of actual robust processing algorithms

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SUMMARY

The first phase of the MT component of the PICASSO (*Project to Investigate Convective Alboran Sea System Overturn*) project was carried out in Southern Spain in Sept.-Nov., 2007. Two different types of magnetotelluric (MT) equipment were used along a profile from the outskirts of Madrid to the Mediterranean Sea through the Betic Mountain Chain. This MT work is part of PICASSO, which is an international, multi-disciplinary project that aims to improve knowledge of the internal structure and plate-tectonic processes in the highly complex three-dimensional region formed by the collision of the African and European plate under the effect of the Mediterranean plate motion.

In spite of low solar activity, time series data of good quality were obtained at most sites due to excellent instrumentation and careful site location. The data were processed using four different robust algorithms, and the different responses have been compared. Pseudosections of responses from this first phase show a remarkably complex subsurface structure dominated by a slightly southwards dipping, conductive slab underneath the region of the External Betic Chain. Strike direction, which varies along the profile and with depth due to the intricate morphology, has an enormous impact on the acquired responses and thereby provides a challenging framework for MT data interpretation.

Keywords: Magnetotellurics, Robust processing, Plate-tectonics, Betic Chain

INTRODUCTION

Due to its distinct tectonic regime, the western Mediterranean region is one of the most appropriate natural laboratories to study complex plate-tectonic processes. Converging European-African plate motions interacting with orthogonal motion of the Alboran microplate yields a highly complex and therefore interesting area to investigate tectonic processes. These processes formed the arc-shaped Betic-Rif mountain system spanning from southern Spain through Gibraltar to northern

Morocco.

Due to this complex three-dimensional structure the western Mediterranean region has been chosen as the area of investigation for the PICASSO (*Project to Investigate Convective Alboran Sea System Overturn*) project. The PICASSO project has identified a variety of geoscientific problems to be investigated in this region. The specific aims of the MT component, amongst others, are to define the geometry of the upper mantle and the lithosphere-asthenosphere boundary, and to enhance knowledge about the process of recycling the lithosphere back into the mantle. At the same time, major geoscientific questions, such as the reason for the elevation of central Spain and the lack of a mantle root beneath the High Atlas Mountains, will be addressed. The area north of the Alboran Sea is the target of the first phase of the MT acquisition within the PICASSO project.

GEOLOGIC SETTING

The main tectonic elements in the region of the Western Mediterranean are the compressional European and African plates and the 'Alboran microplate' (Chalouan et al. 2006) beneath the Mediterranean Sea. While the African and European plates have a recent NW-SE convergence rate of 4 mm/a (DeMets et al. 1990), with an additional anticlockwise rotation of the African plate, the Alboran plate is moving to the west-southwest (Chalouan et al. 2006; Dewey et al. 1989) (figure 1). These tectonic processes formed the Betic-Rif mountain system, and are thought to be part of the active subduction process underneath the



Figure 1 Main tectonic elements of the Western Mediterranean, from Chalouan et al. 2006. The red line displays the profile carried out during the PICASSO project 2007.

Gulf of Cadiz (Gutscher et al. 2002) and part of the modern, ongoing lithospheric delamination beneath the Alboran Sea (Seber

et al. 1996, Calvert et al. 2000). The Betic Chain to the north of the Alboran Sea was formed as a consequence of the convergence between the African and Iberian plates since late Cretaceous time (60 My) (Platt and Vissers 1989). It stretches from the Gulf of Cadiz to the Cabo de la Nao with an ENE orientation, parallel to the southeastern coastline of Spain. The dominant antiformal-synformal relief of the Internal Zones of the Betics is related to tectonic structures active since the Late Miocene. The antiforms correspond to east-west elongated mountains (Sierra Nevada, Sierra de los Filabres, Sierra de Gador and Sierra Alhamilla) and the synforms correspond to elongated depressions between these mountain ranges (Pedrera et al. 2006) (see figure 2).

MAGNETOTELLURIC DATA

Acquisition of magnetotelluric (MT) data along a 400-km-long profile, with an approximate north-south orientation, was carried out between October and November 2007 as PICASSO Phase I (figure 3). Data from 25 Phoenix Geophysics broadband MTU stations and 20 Lviv long-period LEMI stations were collected, with site separations of 10 km and 20 km respectively (figure 3).

The data acquired are generally of good quality due to the excellent instrumentation and to careful selection of locations for the recording sites as far away from visible sources of cultural noise as possible. However, due to the low solar activity, and thus weak MT source signal, even distant sources of noise (e.g. the Spanish DC electric rail system) seriously degraded the signal-to-noise ratio at some sites. Analyzing such noisy data required elaborate data interpretation skills and processing software.



Figure 2 Geological sketch map of the Betic Chain, from Marti 2006. Points denote site locations of the PICASSO project 2007.

The broadband MT data were processed using proprietary processing software from Phoenix Geophysics, Inc. (Phoenix Geophysics 2003 cascade decimation based on Wight and Bostick (1980) with robust modifications based on Jones' approach (Jones et al. 1989)) and Egbert's (Egbert 1997) robust processing algorithms. The long period data were processed using Jones's (Jones et al. 1989) and Chave's (Chave and Thomson 2004) robust processing algorithms. Comparing the results from the different processing programs reveals that the programs produce approximately similar results, but differ in their ability to deal with certain problems like poor data in the dead band and their sensitivities to outliers and leverage points.

The long period systems used in this project (LEMI) measure four independent electric channels (north-to-ground, east-to-ground, south-to-ground and west-to-ground) besides the standard north-south and east-west ones, providing more options for selecting electric channels and reducing the risk of losing data

when doing long term deployments. This allowed extended investigation of the subsurface resistivity structures, in addition to typical MT data examination. Utilizing the length-related sensitivities of the different electric dipole combinations can reduce galvanic distortion effects. The simplest of these are static shifts (Jones 1988), caused by confined resistivity anomalies smaller than the dipole length, as described in the electromagnetic array profiling (EMAP) method by Torres-Verdin and Bostick (1992).



Figure 3 Location of the Magnetotelluric recording stations utilized during the PICASSO fieldwork campaign in Spain, 2007. Arrows denote the strike direction obtained at a station.

After deciding on the best estimates of the responses for each site and system, we merged colocated responses. This allows us to obtain resistivity information from the upper crust to the upper mantle.

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of The tensor decomposition software McNeice and Jones (2001) was used to identify the dominant strike directions of the subsurface, and distortion parameters given by the twist and shear angles. Plotting the dominant strike direction for each site reveals its variation along the profile (figure 3). On the basis of this outcome, three groups of sites were chosen and the tensor decomposition performed for each group. The results of the combined tensor decomposition reveal that geoelectric strike varies with both depth and along the profile (figure 4). Fitting a distortion model to the data yields a dataset suitable for 2D inversion within reliable confidence limits.

Pseudosections of the data suggest a highly conductive, slightly southward-dipping slab in an otherwise relative conductive subsurface (figure 5). The boundaries of the slab coincide with the location of the northern and southern borders of the External Betics.

Strike angle

41

33

Site

13 - 31

Site

- 1

Site 01

90

45

0

-45

-90 90

45

0

-45

-90 90

45

0

10⁻³ 10⁻²

10⁻¹

-45 -90

Figure 4 Strike angle of three groups of sites (site location shown in fig. 3), obtained by combined MT tensor decomposition for all sites of each group. The values of the strike angle have been averaged over one decade with an overlap

10⁰

Period (s)

10¹

10²

10³

of 0.3 decades. It is apparent that the strike angle varies along the profile and with frequency (and therefore with depth).

CONCLUSION AND DISCUSSION

The first phase of PICASSO, carried out in southern Spain, provides a challenging MT dataset that has been used to test and compare different robust processing programs and MT data analysis methods. Comparison reveals that the different processing algorithms result in broadly similar results for the subsurface structures, but differ in details, for example in the ability to process data from the dead band or the sensitivity to outliers and leverage points.

Decomposition of the impedance shows that the MT data contain effects produced by variation of strike direction along the profile and with depth, in addition to the effects of normal two- and three-dimensional structures. The responses reveal a highly complex structure in the subsurface underneath the profile investigated. This indicates the complex tectonic processes inherent to the Betic-Rif mountain system. Two-dimensional inversion models will give more precise information about the geological structures.

Insight into the geological structures obtained during the first phase of PICASSO, studying the African-European-Alboran plate-tectonic processes, will be further augmented when data from the second phase are available. This phase will be carried out in Morocco in 2009. With the combined dataset, it will be possible to tackle challenging problems like the extraordinary behaviour of the lithosphere-asthenosphere boundary (LAB) un-

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derneath the Betic-Rif mountain system.

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Figure 5 Pseudosection of the Apparent Resistivity (TE-mode), revealing a highly conductive slab, located near the surface close to the borders of the external Betic Chain and dipping southwards with depth.