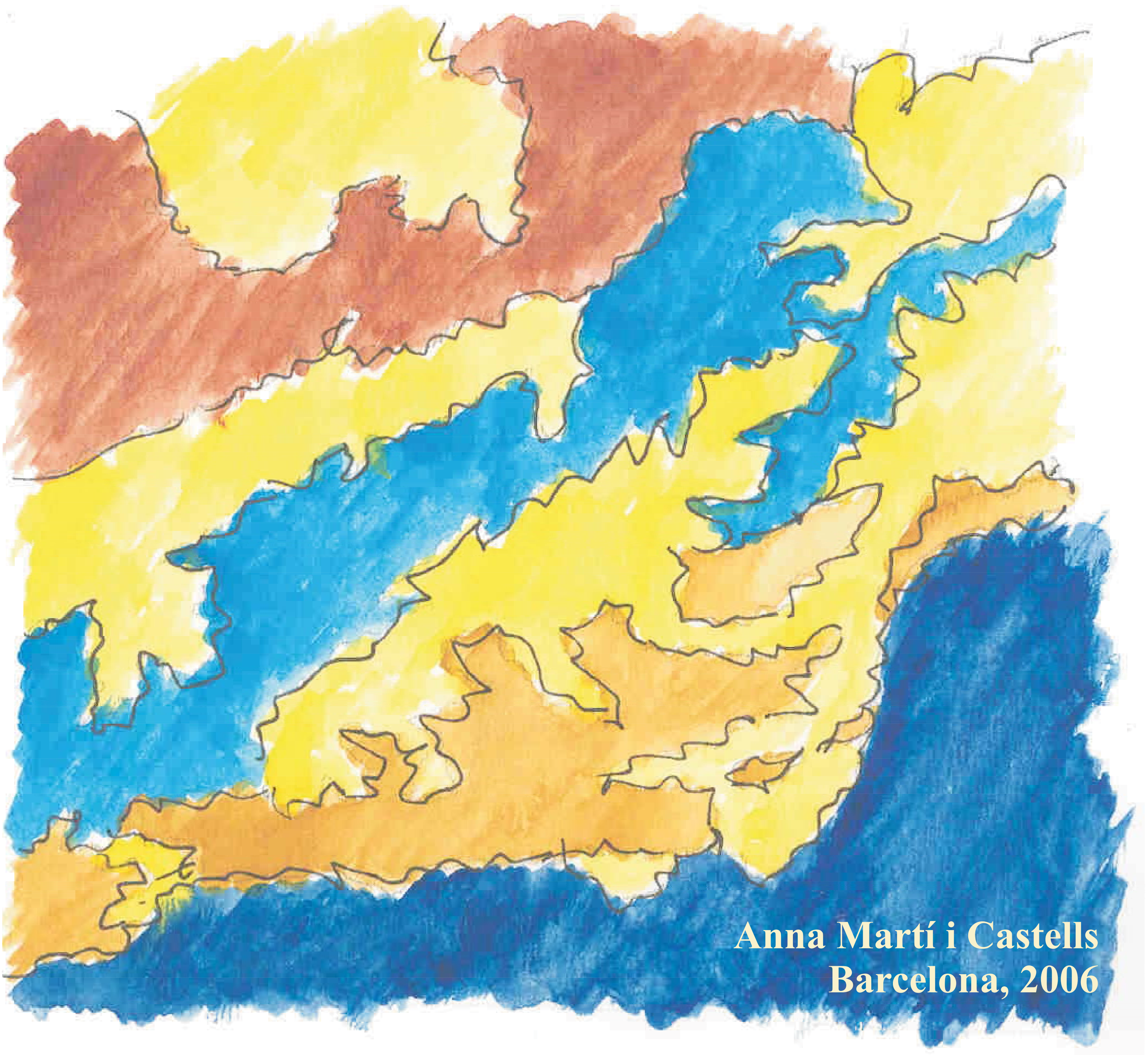
Ph.D. Thesis

Universitat de Barcelona
Departament de Geodinàmica i Geofísica

A Magnetotelluric Investigation of Geoelectrical Dimensionality and Study of the Central Betic Crustal Structure



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Introduction

Since the 80s and 90s, most crustal and lithospheric studies include - complementary to other geophysical properties – an image of the electrical conductivity of the Earth that provides important constrains on the geological structure and tectonic evolution of a particular area (e.g. Jones, 1992; Hjelt and Korja, 1993; Brown, 1994; Nover, 2005; and references therein). Because of its wide range of variation, the electrical conductivity provides independent information on the physical properties of the crust, almost inaccessible by more traditional methods such as seismic.

The electrical conductivity of rocks is very sensitive to a wide range of petrological and physical parameters: the abundance and distribution of conductive minerals, the volume and shape of pores, and the conductivity of pore fluids. Within the firsts hundred meters these properties are controlled by the surface the lithology, groundwater content and salinity, fracture distribution and clay content. In the Earth's crust, these properties are affected by geological units, the concentrations and connectivity of metallic minerals and graphite, fracture zones, aqueous phases, and temperature. In the upper mantle, other processes, like the degree of chemical depletion, metasomatism, partial melting, and possibly hydrogen diffusion play an important role.

Information on electrical conductivity of the subsurface at a crustal or deeper scale is inferred mainly from magnetotelluric surveys. The magnetotelluric method (MT) utilises natural electromagnetic energy to electrically characterise Earth structures. Its main strengths are that its allowance for a broad range of penetration depths, its sensitivity to lateral and vertical electrical conductivity variations and its capability of imaging volumetric structures.

In this context, the Betic Chain (Spain) is an Alpine orogen located at the western end of the Mediterranean, in which MT studies can improve the knowledge of its complex crustal structure through the resulting geoelectric models. Data from the central part of the Betics, from a previous survey and from the survey performed during this thesis (2004), have been processed, modelled and interpreted.

An important part of any MT study is the dimensionality analysis of the data, in particular of the magnetotelluric tensor, which gives rise to modelling the geoelectric structures as 1D, 2D or 3D.

MT data can be affected by distortions, which mask the dimensionality of the geoelectric structures. These distortions must be identified and removed, or alternatively be included in the models.

Several methods have been presented on dimensionality analyses and the identification and removal of distortions, which have greatly contributed to the development of the MT method. However, most of these methods focus on a specific type of dimensionality, using a particular set of parameters that characterises only a part of the magnetotelluric tensor. As a consequence, sometimes these methods have been misused, as opposed to limiting their application to being a tool for hypothesis testing, resulting in an automatic 2D modelling of the data. Instead, a more careful analysis of the data dimensionality should be performed, limiting the subsets of data for which certain hypotheses are valid.

In this respect, the first part of the thesis concentrates on dimensionality analysis.

Some well known as well as some more recently published methods have been studied and compared, with an emphasis on solving the problems associated with real data, where the errors and the departure from ideal cases must be considered. All this work has been guided by the idea that it is necessary to work with as much information as possible from the data, in this case, the components of the MT tensor, and to assume that data are 3D, with particular cases that can be 1D or 2D. This research has been performed using the COPROD2 and the BC7 datasets (both well known by the MT community), data from synthetic models and data acquired in the central Betic Chain.

The second part of the thesis focuses on the magnetotelluric study of the central Betic Chain. It comprises data acquisition and processing, dimensionality analyses - in which parts of the methodological improvements done in the first part were applied - and modelling. Thanks to the advances in computing tools, especially in speed and memory storage, a 3D geoelectric model of the central Betic crust could be constructed. Prior to this a revision of the existing 2D model was made and new 2D models were created as a preview of the 3D model.

Thus, the goals of this thesis can be summarised as two-fold: to conduct a thorough study of the MT data dimensionality methods and to construct a useful tool to perform this analysis on real data; and to obtain a geoelectrical model of the central Betic crust from a complete study of the old and newly acquired MT data.

This dissertation has been organised into three main parts:

Part I: "Introduction to the Magnetotelluric Method". This consists of an introduction in which the basis and main elements involved in a MT study are described (chapter 1). In chapter 2, the methods used in dimensionality analyses of MT data are provided and reviewed in more detail. Specifically, WAL invariants, Bahr parameters and the magnetotelluric phase tensor methods are described, as these are the basis for the methodological aspects developed in this thesis.

Part II: "Methodological Contributions to Geoelectric Dimensionality". In this part, the investigations carried out in this thesis on dimensionality analyses are presented. Thus, chapter 3 shows how to implement WAL invariants criteria to analyse geoelectric dimensionality in noisy data, with a special emphasis on error propagation and the choice of threshold values. The resulting method was developed as a computing program (WALDIM). Chapter 4 proposes a unification of WAL and Bahr criteria, with the addition of a new parameter to the last one, allowing compatibility. To complete this part, chapter 5 presents a study of the magnetotelluric phase tensor as a new tool to investigate data dimensionality. It explores the relationships of this new tool with other methods and its effects on the data with consideration of its strong and weak points.

Part III: "Magnetotelluric Study of the central Betic crustal structure". The entire MT research carried out in the Central Betic Chain is shown here. The geological setting and the previous geophysical studies are reviewed in chapter 6. Chapter 7 explains the data acquisition and processing, which involves the use of different instrumentation and processing tools, as well as a description of MT data responses and quality. Chapter 8 presents the results of dimensionality analysis obtained from WALDIM software, which were contrasted with other methods. Chapter 9 revises the previous 2D MT model done in the area and presents the results from new 2D models obtained from different 2D inversion algorithms in the Internal Zone of the Betics. Chapter 10 describes the construction of the 3D model, its results and the responses' misfits. This chapter finishes with the interpretation and discussion of the resulting 3D model.

Finally, the conclusions of the thesis and the perspectives of future MT research, both in the context of dimensionality and the structure of the Betic Chain, are presented.

This dissertation is complemented with six appendices, which provide additional information on: error expressions, information on the datasets used, details of the acquisition and responses of Betics MT data, comparisons between model and data responses and a mathematical proof.

Part of the work developed in this thesis has been published as three papers in Geophysical Journal International:

Ledo, J.J., Queralt, P., Martí, A. and Jones, A.G., 2002. Two-dimensional interpretation of three-dimensional magnetotelluric data: an example of limitations and resolution. *Geophys. J. Int.,* **150**, 127-139.

Martí, A., Queralt, P. and Roca, E., 2004. Geoelectric dimensionality in complex geologic areas: application to the Spanish Betic Chain. *Geophys. J. Int.*, **157**, 961-974.

Martí, A., Queralt, P., Jones, A.G. and Ledo, J.J., 2005. Improving Bahr's invariant parameters using the WAL approach. *Geophys. J. Int.*, **163**, 38-41.

A forth paper on the 3D modelling and interpretation of the central Betics MT data is presently in preparation.