Chapter 1

Introduction

The Institute of Geological Sciences of the Free University of Berlin has since 1982 been intensively involved in investigations that aim to get a deeper understanding of the processes controlling the subduction orogen of the South American Andes. First studies were conducted by the Berlin research group *Mobility of Active Continental Margins*. After 1993, the engagement was expanded by installation of the collaborative research center SFB267 *Deformation Processes in the Andes*.

Most investigations concentrated in the Central Andes of north Chile, southwest Bolivia and northwest Argentina, where the subduction orogen reaches dimensions which are unique on earth for an oceanic-continental plate convergence zone. The enormous extent is not confined to the visible part of the orogen: By application of various seismic methods to data from various experiments, crustal thicknesses partly exceeding 70 km were estimated, which also manifests itself in a very strong negative Bouguer anomaly (~450 mGal). Encountered seismic low velocity anomalies, zones of high seismic attenuation, high v_p/v_s-ratios and diffuse reflectivity, and not least high conductivity anomalies characterize this extremely thickened crust as a zone of rheological weakness (chapter 3 gives an overview). The image of geophysical parameters in the subsurface of the forearc and volcanic arc maps actual rheological geometries within the subduction regime and gives insights into ongoing physical and chemical processes, such as dehydration or phase transitions. Recently, also the southern Andes around latitude 39°S have become subject of geophysical investigation, which involves also electromagnetic measurements, carried out in 2000.

In electromagnetic experiments, as also carried out in the mentioned period in the Andes, the mostly natural temporal variation of the electromagnetic field is recorded at a certain number of sites. External electromagnetic variations diffuse into the conducting earth while inducing currents. The secondary field of these currents contributes to the total field measured at the earth's surface. The relations (transfer function) between components of the electromagnetic field are functions of the subsurface conductivity distribution and frequency. Data analysis aims at determining these relations, analytical and/or numerical modelling aims at reproducing them (see chapter 2). Usually only local transfer functions are subject to this procedure, namely impedances, relating the horizontal electric to the horizontal magnetic field (magnetotellurics, MT), and geomagnetic transfer functions relating the vertical to the horizontal magnetic field components (geomagnetic depth sounding, GDS). These techniques exploit only the simultaneity of data recorded at each site. Yet, in the period range considered in this work (tens of seconds up to several hours), data of campaigns are generally recorded at a number of stations at the same time, and thus to a high degree simultaneous. This simultaneity can be taken advantage of for two objectives: i) to separate signal from noise applying a multivariate analysis, allowing also for detection of noise which is coherent throughout the study area, and ii) to deduce transfer functions between any components within the array, which can involve both, local and inter-station transfer functions. Among the latter, transfer functions which relate the total geomagnetic field to the horizontal field of a selected reference station are of particular relevance. To give a prominent example, *Schmucker et al.* [1966] discovered the Andean conductivity anomaly by such geomagnetic *perturbation* analysis.

When analyzing inter-station transfer functions, usually one common reference field is chosen, which can be either a synthetic field, e.g. the average horizontal magnetic field of the array, or the horizontal field at a selected reference station, which is preferably located in a relatively normal conductivity section, so that inter-station transfer functions reflect the anomalous conductivities below the other site.
In the study areas, the former is not reasonable, since because of the highly conductive ocean and other encountered large-scale anomalies, the average horizontal field cannot be regarded as normal. To select one common reference station for all sites, as it would be aspired, is on the other hand impossible without limitations on data quality and physical content: the data are recorded within different campaigns, and these campaigns overlap only partly in space. Also, the simultaneity of the data from separate campaigns is not hundred percent (chapter 4). A combination of simultaneously processed data was therefore only done for a presentation of the synthetic array data, which turned out to be very instructive (chapter 5).

In this work, inter-station geomagnetic data are not just considered to display data and confirm impedance data analysis and modelling results, but is regarded as a means to constrain the conductivity distribution since these data are less affected by quasi-static electromagnetic effects which can strongly complicate impedance data analyses. Most data from the campaigns are aligned along profiles, traversing the Andes from the Chilean coast to at least across the active volcanic arc. Analysis of electromagnetic data by isotropic 2-D modelling since a few years has been almost exclusively performed by employing effective inversion algorithms which iteratively adjust synthetic forward responses of discrete models to input data. Since none of the commonly used algorithms includes an inversion of inter-station geomagnetic transfer functions, corresponding extensions have been implemented in this work in the recently published REBOCC inversion code of *Siripunvaraporn and Egbert* [2000] (chapter 6). Inverting numerical data from two synthetic models, the potential of inter-station transfer function analysis resp. of an inversion of such data is demonstrated. Since data from the northern study area cannot be related to one common reference station, an inversion of data with various references has also been implemented. This formalism completely omits the strict distinction between normal and anomalous field. Questions on the uniqueness of electromagnetic inversion solutions are also addressed in this chapter.

The electromagnetic data used in this work were previously analyzed by *Echternacht et al.* [1997], *Schwalenberg* [2000], *Lezaeta* [2001] and *Brasse et al.* [2002] (Central Andes), and *Brasse and Soyer* [2001] (Southern Andes). Essential parts of some of these studies are based on bimodal 2-D impedance inversions, which also revealed a vast electrical conductivity anomaly below the Bolivian Altiplano (section 3.1). The 2-D inversions presented in chapter 7 aim at getting insights in the conductivity distributions by examining the information contained separately in the five types of transfer functions which remain unequal zero above true 2-D structures. This part of the work addresses the questions, whether an incorporation of magnetic transfer functions in the analysis does significantly change modelling results, and to what extent inter-station geomagnetic data bear additional information to local geomagnetic data.

Geomagnetic data from the Southern Andes have clear signature of two-dimensional anisotropy of an horizontal strike, which differs from the recent structural tectonic strike (chapter 5). Focussing on the analysis of those transfer functions, which lead to the idea of an electrically anisotropic subsurface, 2-D anisotropic forward modelling is performed by adjusting only this data set (chapter 8). This is regarded as a first but important step towards a more complete physical understanding of all transfer functions derived for this study area. It is also illustrated, why continental margins are most suitable environments for the detection of continental anisotropic structures by an analysis of geomagnetic variation.

The various aspects of this work are discussed in chapter 9, and shortly summarized in the last chapter. The following chapter gives an introduction to the physics of geo-electromagnetic induction, providing a connection to array data analysis, which is sketched in section 4.1.