Chapter 9

Regional 2-D modeling

The goal of this chapter is to obtain the regional conductivity values through the 2-D approach, and consider these either as background values or as structures to be verified under a full 3-D modeling. First, the ocean structure was constructed for a 2-D forward modeling in order to investigate how far its response influences the different tectonic units and to find out whether this effect can be subtracted from the field data (section 9.1).

2-D inversion of MT data from the Ancorp profile (at 21°S) was realized, comprising the regions between the coast and the western Altiplano. The inversion was performed with the code of Mackie et al. [1997] with the aim of obtaining the regional conductivity structures. The inversion was also performed by including a conductive oceanic slab as *a priori* information, to test whether such structure is sensitive for the MT data and the magnetic transfer functions (section 9.2.1).
Considering the models resulted from the inversion, the sensitivity of the MT-data and magnetic transfer functions to the variations of the main conductivity zones (section 9.2.2) was further tested. The TE-mode of the MT-data was discarded from the sensitivity analysis because it is strongly distorted by 3-D effects (sections 7, 8). Therefore 2-D models are proposed for the two main WE profiles (Pica at 20.5°S and Ancorp at 21°S; section 9.2.3) which are considered for a 3-D modeling (Chapter 10).

9.1 Investigation of the ocean effect

The influence of the ocean in the MT-phase and GDS data has been investigated by a 2-D model including the bathymetry and topography at latitude 21°S (Ancorp). The conductivity structures beneath the ocean follow the general characteristics of the 2-D model defined for the Pica profile (20.5°S) by Echternacht [1998]. Beneath the continent a layered earth model was considered (see fig.9.1).
The model responses are compared with the data for single periods in WE traverses as a function of the site location (figs.9.2, 9.3).

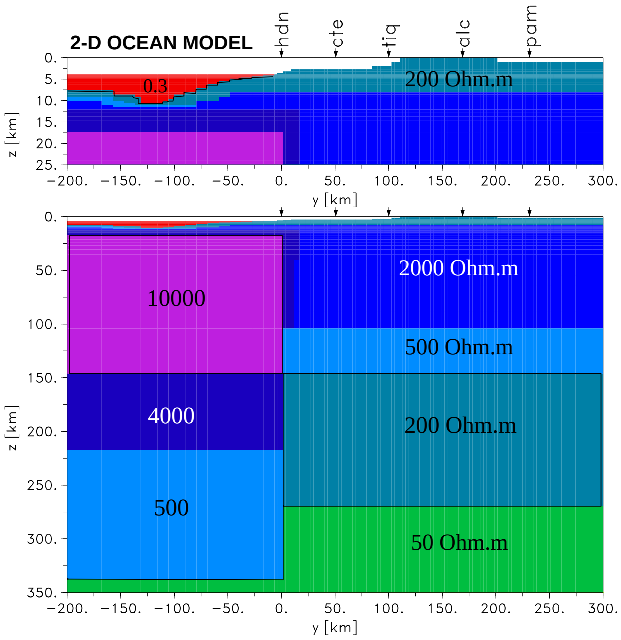

Figure 9.1: The 2-D forward model considered for the ocean effect study. The sites shown correspond to the Ancorp profile located at the different geological unit boundaries: HDN in the coast line, CTE in between the Coastal Cordillera and Precordillera (PC), ALC in between PC and the Western Cordillera (WC) and PAM between WC and the Altiplano.

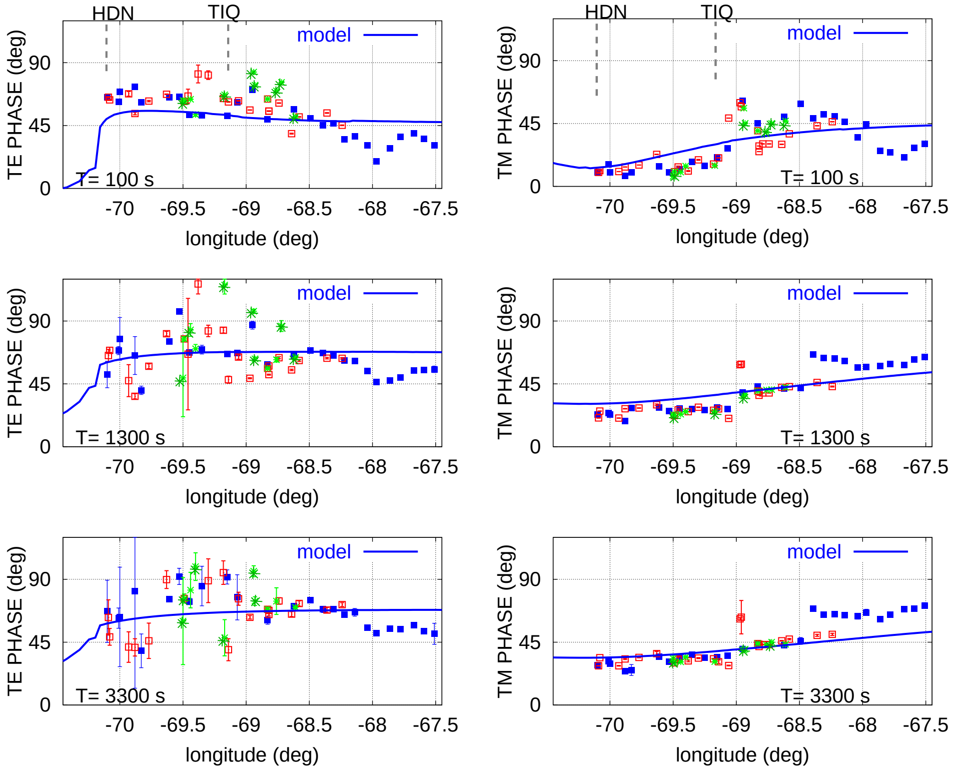

Figure 9.2: Impedance phases from the ocean model response (lines; model in fig.9.1) compared with the field data in the measured coordinate system (NS), shown for three different periods (100, 1300 and 3300 s from top to bottom) as function of site location longitude (WE). Site HDN and TIQ are located at the coast line and the western Precordillera, respectively. The TE-mode phases in the Coastal Cordillera (-70°) are the eigenvalues explained in section 7.3. *Dark* and *open squares* are the data from the *Ancorp* (21°S) and *Pica profile* (20.5°S), respectively. The *stars* correspond to the sites located *between both profiles*. *Left:* TE-polarisation mode. *Right:* TM-polarisation mode.

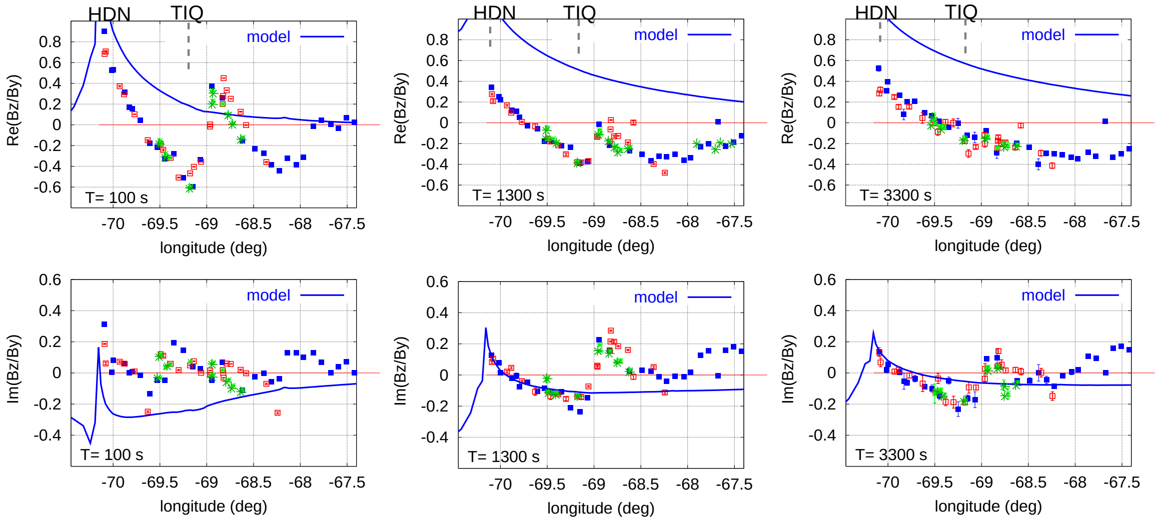

Figure 9.3: WE component of the magnetic transfer function (B_z/B_y) from the ocean model response (lines) compared with the field data in the measured coordinate system (NS), shown for three different periods (100, 1300 and 3300 s from left to right) as function of site location (longitude). Site HDN and TIQ are located at the coast line and the western Precordillera, respectively. Different symbols are the data from the different profiles as explained in fig.9.2. *Top:* Real part. *below:* Imaginary part.

All sites of the region have been projected on the traverses. Three periods were selected; 100 s, 1300 s and 3300 s, representative for a short, mid and deep penetration depth, respectively. The data were treated in the measured coordinate system, thus assuming a NS regional strike which is approx. parallel to the coast line. In the Coastal Cordillera, the eigenvalues of the tensor elements have been considered for the 2-D approximation (section 7.3).

In the TE-mode impedance phases of long periods the ocean effect can not be distinguished clearly because they behave in a 3-D manner (fig.9.2). The explanation is the magnetic distortion affecting mostly the phases of this polarisation mode, identified by the current channeling analysis (sections 7, 8). Only in the Coastal Cordillera, at periods <1000 s, is a 2-D approximation achieved through the eigenvalues (section 7.3). Data with large errors and near 90° (or over 90°) are associated with a down bias of the electric field amplitudes due to the strong current channeling.

The TM-mode phases can be identified with an ocean effect[1], which expands to the east with the period, reaching even the Western Cordillera (68.5°W; fig.9.2) at periods >3000 s. The ocean structure therefore seems necessary to be included in the conductivity modeling of the Precordillera and Western Cordillera regions if the long period MT data are to be considered. The east component of the magnetic transfer functions (B_z/B_y; fig.9.3) is also influenced by the ocean, extending to the east with the period. It is seen in the parallel curves between data and model responses. The shift of the curves with respect to the data indicates an additional effect. At short and mid periods the steep trend change of the data at 69°W (Precordillera) indicates the influence of another conductor, which has been already identified as a shallow high conductivity structure inducing anomalous magnetic fields (section 8.2).

It can be concluded that the TM mode of the MT data from the Coastal Cordillera is mostly

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[1] By the TM-mode, i.e., magnetic field parallel and electric field perpendicular to the NS coast line, the ocean induces WE and vertical current flows into the continent

affected by the ocean (70-69.5°W; fig.9.2); thus any other conductivity structure located further inside the continent (Precordillera) has a negligible effect on this region. The magnetic transfer functions, in contrast, are seen to be affected by additional continental conductivity structures (fig.9.3).

9.1.1 The coupling between the ocean and the structures between the Precordillera and the Altiplano

A subtraction of the ocean effect can only take place if the electromagnetic (EM) fields are decoupled from the ocean currents in the region of interest.

The ocean is assumed to be a 2-D electrical structure with a NS regional strike (approximately parallel to the coast line); therefore the estimation of its induced EM-fields by a 2-D model algorithm is plausible.

The investigation of the ocean effect exerting either an inductive or electrostatic effect upon the Precordillera (PC) and the Altiplano (AP) was realised by comparing the 2-D ocean model (fig.9.1) with a model including buried conductive structures beneath PC and AP (fig.9.4). The latter model was obtained by taking the Altiplano anomaly from the 2-D inversion result, while the Precordillera anomaly was constructed by trial and error, taking initially its upper depth from the thin sheet model (section 8) to explain the magnetic transfer functions. In section 9.2 are presented the alternative models for the Precordillera anomaly, where its depth is the primary variable to the sensitivity test. The model considered here corresponds to a conductor reaching an intermediate depth. This will be referred to here as the "complete" model, as opposed to the "ocean" model. All responses were computed with the 2-D forward algorithm of finite differences included in the inversion code of Mackie et al. [1997].

Of course, the complete model is an approach just for the Precordillera, since 3-D structures have been identified here at least at shallow depths. On the other hand, the NNW-SSE vertical thin dike conductors identified in the Coastal Cordillera (which are not included here) are assumed to have a negligible effect in the Precordillera and to the east since these local dikes were identified as a galvanic distorter (i.e, they exert a local electrostatic effect; section 7). Therefore, the complete model should satisfactorily test if the ocean effect can be removed from data located to the east of the Coastal Cordillera (fig.9.4).

If the ocean and the conductivity structures beneath PC and AP are decoupled from each other (i.e., an electrostatic effect upon the structures), then the magnetic transfer functions (or tipper) from the ocean model on one side and that of the continental structures on the other side can be arithmetically added to yield the responses of the "complete" model (e.g., Weaver and Agarwal [1991]). Otherwise, if ocean and continental structures are coupled (i.e., 2-D inductive effect), the tipper responses can not be simply added. The ocean effect study was accounted for under this criterion by comparing the tipper[2] responses of the complete model (fig.9.4) with the arithmetic sum of the responses of the complete model without ocean and those of the ocean model alone (fig.9.1).

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[2] The term tipper refers to the magnetic transfer functions

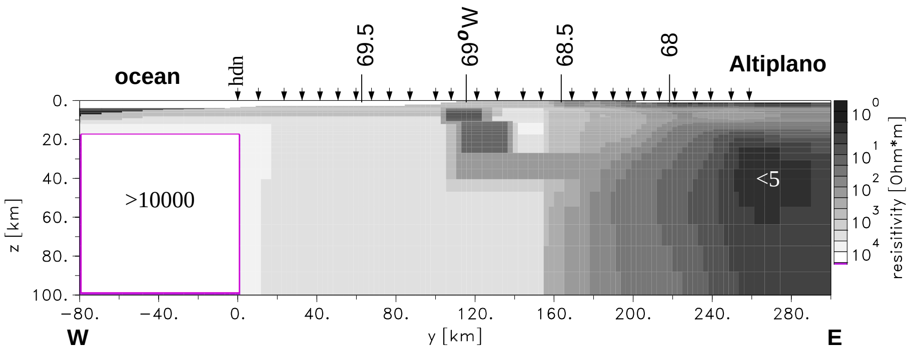

Figure 9.4: The "complete" model considered for the coupling effect study between the ocean and the continental structures. The main structures are located in the Precordillera (69°W) and Altiplano.

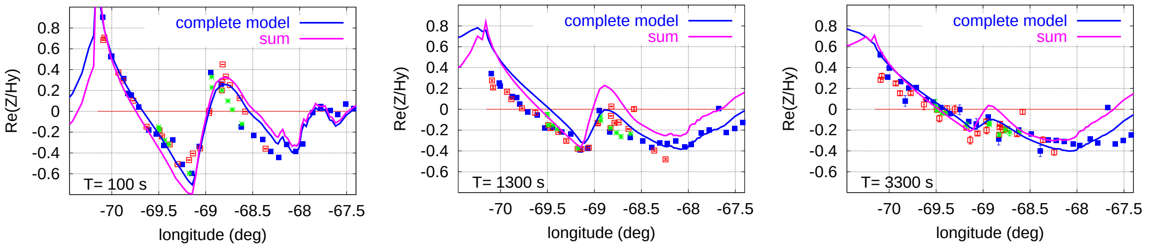

Figure 9.5: Real parts of the WE component of the tipper function as a function of the site location (longitude). From left to right are shown three different periods, representative for short, mid and long penetration depths (100, 1000, 3300 s). The curves are the responses of the complete model (blue line) and the responses sum of the ocean and the continental conductivity structures (red or gray line). Different symbols are the data from the different profiles as explained in fig.9.2.

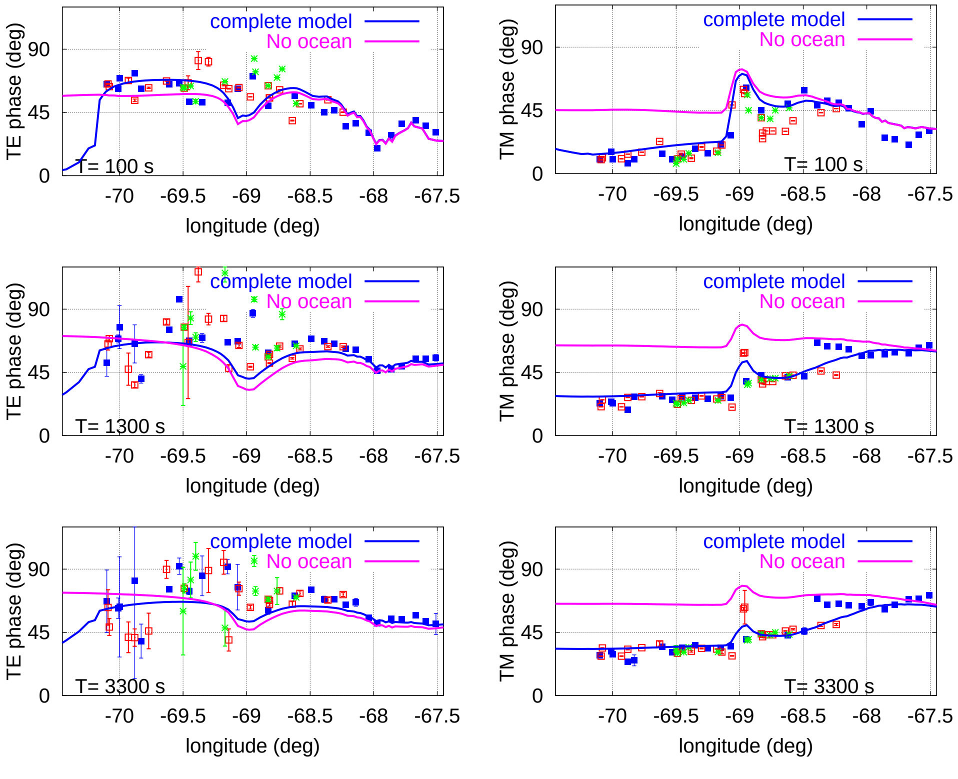

Figure 9.6: Text in next page.

Fig.9.5 allows a comparison of the real parts of the tipper functions from the complete model with that from the sum of the responses between the continental structures and the ocean independently. Both curves are shown together with the measured data[3]. The format of the plots are as in the previous section (e.g., fig.9.2). It can be concluded that the summation, i.e., the ocean effect subtraction, is valid at short periods (<700 s) in the continent.

Figure 9.6 (previous page): Impedance phases as function of site location (longitude). The curves are the responses of the *complete* model (blue line) and the responses of this model *without the ocean* (red or gray line). From top to bottom are shown the three representative periods (100, 1300 and 3300 s). Different symbols are the data from the different profiles as explained in fig.9.2. The field data are in the measured coordinate system (NS) or are the eigenvalues on the coast. *Left:* TE-polarisation mode. *Right:* TM-polarisation mode.

The criterion mentioned above regarding the decoupling treatment was not considered for the MT data since the impedance is the ratio between the electric and magnetic field, which both behave differently in the presence of a conductivity source. In the TM-mode, the magnetic field is uniform while the electric field changes discontinuously across a conductivity interface, dropping at the side of higher conductivity. The higher the conductivity contrast, the stronger will be the change in current flow (e. g., Vozoff [1987]). By the TE-mode, in contrast, the magnetic and electric fields are both continuous at the interface. The first increases while the latter decreases in the region of higher conductivity. Both fields return (differently) to the normal field values with increasing distance from the interface (in terms of a skin depth) as well as with period (Chapter 6; fig.6.1).
Therefore, the ocean effect on the impedance phases was investigated by comparing responses of the complete model that with the ocean subtracted. If the structures were decoupled, then the impedance phase curves of both responses should be equal, provided that the anomalous magnetic field is negligible. This can be easily demonstrated: assuming that the total electric field E (from the "complete" model) is observed electrically far from the ocean so as to have an electrostatic effect D_e produced by the ocean, then $E = D_e \cdot E_r$ (where E_r is the electric field which would be induced without the ocean), while the total magnetic field $B = B_r$ is not affected. Then the total impedance phase is $arg(Z) = arg(E/B) = arg(E_r/B_r)$, since D_e is real.
Figure 9.6 illustrates the MT impedance phases of the complete model response versus the responses of the model with the ocean subtracted. The curves are compared with the measured data. The TE-mode phases of both model responses are clearly similar in the Precordillera (69°W) and east of it. The TM-mode phases, however, become dissimilar with increasing period, reflecting the ocean effect on the WE electric field component at these longitudes. This reflects that the coupling between two separate 2-D conductive bodies is stronger for the electric field component crossing the conductivity contrast (which is not continuous there), where charges are concentrated at the more conductive interface, producing a vertical deviation in current flow (Vozoff [1987]).

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[3] Imaginary parts are not treated in the analysis because they behave differently from the real parts under the influence of 3-D structures. In the 2-D approach the real parts of the WE component are more understandable since they physically represent vectors pointing away from good conductors.

Conclusions

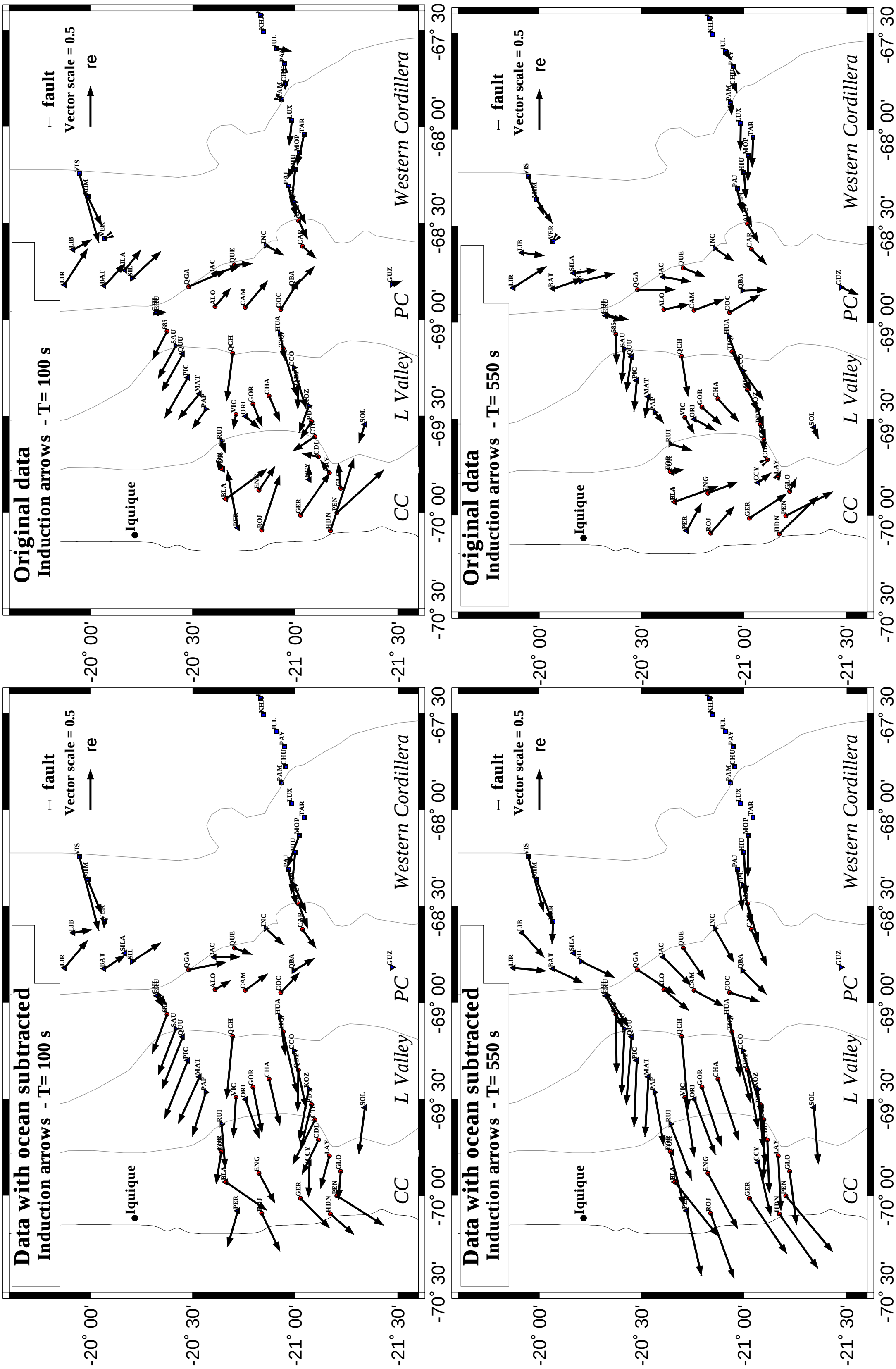
The following can be concluded concerning the coupling effect between ocean and the Precordillera−Altiplano conductivity zones:
1) The TE-mode phase responses are almost insensitive to the ocean effect. This means a model study without the ocean suffices to explain the TE-mode phases in the Precordillera and to the east.
2) The TM-mode phase responses show to be affected by the ocean at periods >200 s. Thus a complete model should be used to explain the TM-phase data in the Precordillera and AP regions.
3) In the Precordillera (69°W) and east of it, a decoupling effect between the ocean and the eastern conductors for the magnetic transfer functions at periods <700 s has been confirmed. Thus the tipper responses of the ocean model can be subtracted from the WE components of the measured data at these short periods (fig.9.1.2).

In **summary**, the ocean can be subtracted from the tipper functions only at short periods, while the TE-phase data can be treated at all periods for the modeling of the Precordillera and Altiplano structures alone. However, if the TM-phases and tipper functions are to be considered to explain the observed data, a modeling of the whole region is necessary specially for long period data.

9.1.2 Induction arrows subtracted from the ocean effect

It can be observed in fig.9.1.2 that for a period of 100 s the induction arrows subtracted from the ocean effect show few differences from the original data in PC and east of it, while at the 500 s period the differences increase. The real induction arrows tend to point more away from the Altiplano, thus confirming the existence of a highly conductive anomaly beneath this zone, which has already been identified by 2-D inversion modeling (section 9.2).
There are obviously differences between the corrected and the original vectors in the region closer to the ocean, but worth note is the angle reversal of the vectors in the Coastal Cordillera, still pointing SW instead of SE, away from (and apparently perpendicular to) the NNW-SSE thin vertical conductive dike(s) interpreted in section 7. This observation supports the existence of the thin vertical dikes as galvanic distorters (i.e., they exert an electrostatic effect).

Figure 9.1.2 (next page): Real parts of the induction arrows as function of site location, projected on the geographical map along with its geological units (*PC*=Precordillera, *CC*=Coastal Cordillera). Periods 100 s (*top*) and 550 s (*below*) are shown. *Left:* Vectors with the ocean effect subtracted. *Right:* Original data.


Original data
Induction arrows - T= 100 s
Original data
Induction arrows - T= 550 s
Data with ocean subtracted
Induction arrows - T= 100 s
Data with ocean subtracted
Induction arrows - T= 550 s
fault
Vector scale = 0.5
re
Iquique
CC
L Valley
PC
Western Cordillera
-20° 00'
-20° 30'
-21° 00'
-21° 30'
-70° 30'
-70° 00'
-69° 30'
-69° 00'
-68° 30'
-68° 00'
-67° 30'

9.2 Investigation of sensitivity to the regional structures

The regional structures were first obtained through a 2-D approach, applying the 2-D inversion algorithm of Mackie et al. [1997] to the MT data. These background conductivity structures in turn allowed a quantitative 3-D modeling.
The model has been inverted for the data of the Ancorp profile covering the Coastal-, Pre- and Western Cordillera to the first 30 kilometers of the Altiplano (from sites HDN to JUL; see fig.4.1), which comprises the area scope for the 3-D modeling. After several tests, the best inversion results are presented here (section 9.2.1).
From the inversion model it follows to investigate the sensitivity of the measured data to certain regional structures, either known *a priori* from other geophysical/geological interpretations or identified after the qualitative analysis of the conductivity anomalies (section 6.3 and Chapter 8).
The first step was to investigate whether the MT and tipper data are sensitive to a conductivity enhancement of the oceanic slab (section 9.2.1).
Further, the sensitivity analysis (to depth and horizontal extension) focused on the Precordillera anomaly, considering a forward model obtained by joining the ocean model (fig.9.1) to the west with the Altiplano anomaly (taken from the inversion result) to the east (section 9.2.2).

9.2.1 2-D inversion: Can we see the slab?

MT data from the Ancorp profile were used for the inversion, covering west to east the coast region to the first 30 km of the Altiplano. Thus the whole fore- and magmatic- arc and part of the western Altiplano Volcanic Center (APC) have been considered for the modeling.

The model grid has 128x49 cells (horizontal, vertical), taking the bathymetry and topography of latitude 21°S into account. The starting model included an ocean structure (of 0.3 Ωm) as *a priori* information and a homogeneous 200 Ωm half-space, or a 200 Ωm layer to 300 km depth underlain by a 20 Ωm bottom space. After the determination of the optimal trade-off parameters for the inversion of the model, where usually 15 to 20 iterations allowed for convergence to a minimal misfit, the inversion result of the starting model with the 200 Ωm half-space is here shown[4] (top in fig.9.7).
The main features of the inversion model are:
1) High resistivities beneath the ocean ($> 10000\,\Omega$m) and in the Coastal Cordillera (1000 to $10000\,\Omega$m) at crustal and upper mantle depths.
2) A conductivity zone ($10\,\Omega$m) between 35 and 45 km depth beneath the Precordillera (PC at 69°W). The *PC conductor* is surrounded by a low resistivity zone ($20-50\,\Omega$m) between 15 and 80 km depth.
3) A high conductivity zone (HCZ; $< 10\,\Omega$m) beneath the Altiplano (AP; east of 68°W) below 15 km. Also, a HCZ is encountered at the surface.

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[4] The start model with the 200 and 20 Ωm half-spaces showed almost no differences with the former at the first 100 km depth.

The feature beneath the ocean indicated in point 1) has already been interpreted in section 7 regarding a stronger current flow in the upper crust by increasing the resistivities below the ocean. Thereby the ocean contributes to the attraction of more currents by the continental conductors. However, the 2-D inversion algorithm is not able to resolve the shallow thin vertical conductive dike(s) oriented NNW-SSE identified in the Coastal Cordillera, which were found through 3-D modeling to explain the TE-mode data and induction arrows (sections 6.3.3, 7.1) because the MT data have been corrected of such a local 3-D effect (eigenvalues; section 7.3). On the other hand, the 2-D modeling does not include the WE component of the magnetic transfer functions (or induction arrows) in the inversion. Nevertheless, the NS component of the induction arrows have also relevant information with regard to the conductive dikes.

Regarding point 2), the PC conductor solved by the 2-D inversion at mid-low crustal depths does not coincide with the shallow (2 km depth) 3-D anomaly identified beneath PC (section 8.2). The fact that the shallow structure is 3-D makes the 2-D inversion modeling implausible. Therefore the highest misfit after the inversion are encountered in this region (69°W; fig.9.8), especially in the TE-mode which has already been identified to be more magnetically distorted (with phases over 90° sometimes) than the TM-mode, interpreted as a coupling effect between the shallow 3-D conductive zone and a deeper conductive layer (section 8.2). On the other hand, the shallow anomaly was seen to be the source of significant anomalous magnetic fields; thus the tipper functions at short periods contain relevant information with regard to shallow conductors. Evidence for the unfeasibility of the inversion model concerning this shallow conductor can be seen in the discordant tipper functions between the model response and data (fig.9.9), especially at short periods.

In point 3), the anomaly (HCZ) beneath the Altiplano supports the interpretation recovered from the 3-D contour plot images of the distortion parameters regarding an inductive effect increasing with period, associated with a highly conductive zone in depth (section 6.3.2). This HCZ is also in concordance with the inversion model of the Ancorp profile extending to the eastern Altiplano (69.5°W), whereas the Coastal Cordillera data were excluded from the inversion as well as the ocean structure from the start model (Schwalenberg [2000]).

Figure 9.8 (next page): Impedance phases as function of site location (longitude). The curves are the inversion model responses for the homogeneous half-space start model (2D) and the start model with the conductive slab included (slab). Dark squares are the data used in the inversion (Ancorp profile), treated in the measured coordinate system (NS) or are the eigenvalues on the coast. From top to bottom are shown the periods 100 and 1300 s. *Left:* TE-polarisation mode (XY). *Right:* TM-polarisation mode (YX).

Figure 9.9 (next page): Real parts of the WE component of the tipper function as function of site location (longitude). The curves are the forward responses of the MT Ancorp inversion model: from a homogeneous half-space start model (2D) and the start model with the conductive slab included (slab). Different symbols are the data from the different profiles as explained in fig.9.2. From left to right are shown three different periods, representative for short, mid and long penetration depths (100, 1000, 3300 s).

In the 200 Ωm half-space start model an oceanic conductive slab (20 Ωm) was inserted, approximately following the Wadati-Benioff zone, to investigate the sensitivity of the data to a conductivity enhancement of the slab, as were due to a dehydration process. Therefore,

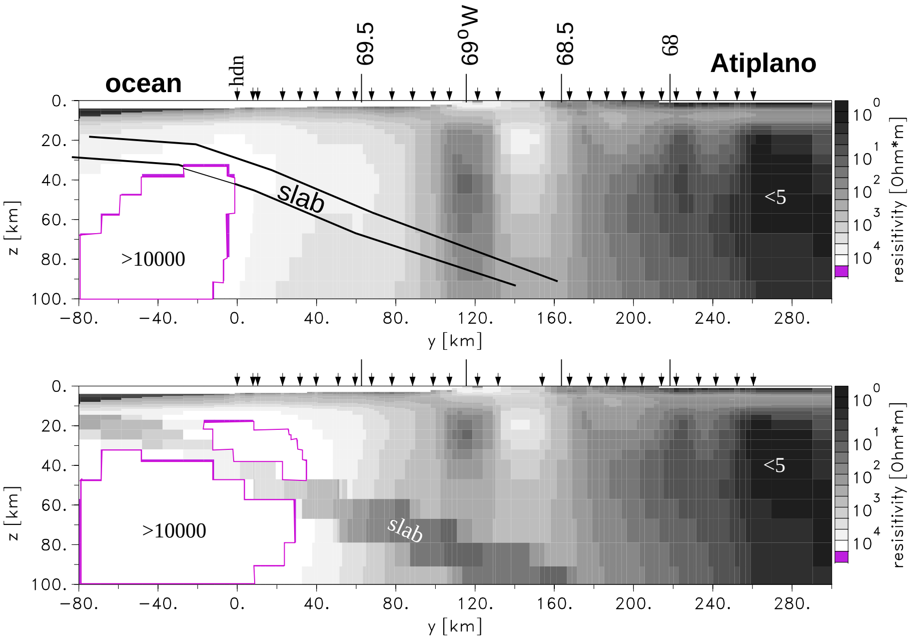

Figure 9.7: 2-D inversion models of the Ancorp profile (at 21°S) including topography and bathymetry of the region. In all start models, the ocean was set *a priori* (0.3 Ωm). *Top:* Inversion result after 20 iterations of an homogeneous 200 Ωm half-space start model. *Bottom:* Result after 20 iterations of a 200 Ωm half-space start model including a 20 Ωm oceanic slab.

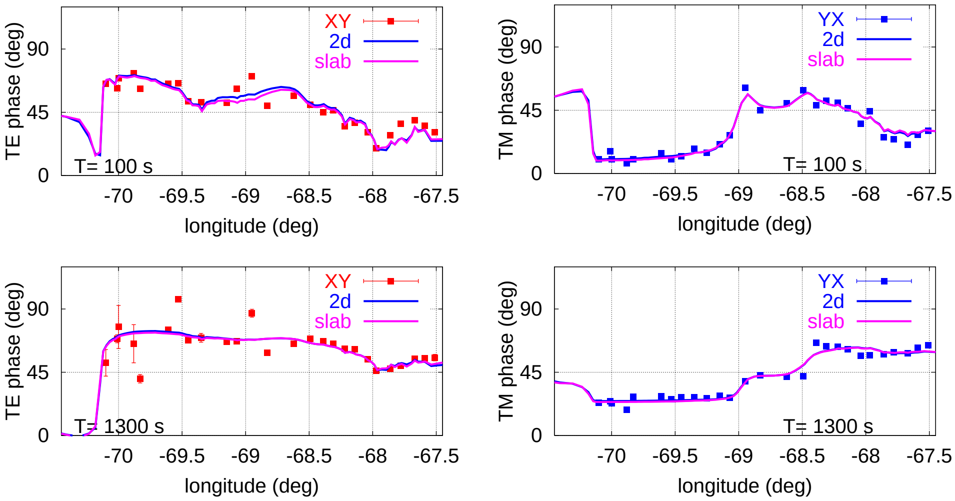

Figure 9.8: Responses of the models shown above. Text in previous page.

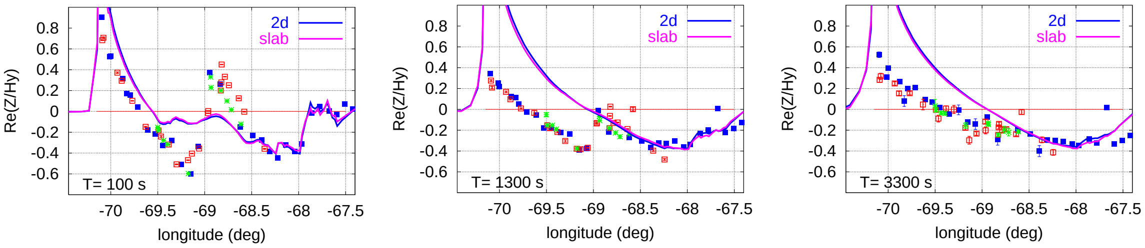

Figure 9.9: Responses of the models shown on top. Text in previous page.

this structure was set as *a priori* information in the inversion in order to let the algorithm define itself the sensitivity of the MT data.
The inversion after the 20th iteration (fig.9.7, bottom) resulted in destroying the conductive slab beneath the ocean and Coastal Cordillera (CC); thus the MT data in CC do not require such a structure. Furthermore, the crustal and upper mantle resistivities are still higher in these regions than in the former inversion model (fig.9.7, top). This is reasonable since the conductive slab (present to the east) also attracts currents from the ocean, thus attenuating the current channeling in the PC conductor. This loss of current can be compensated for by increasing the resistivities beneath the ocean and near coast region in order to have channeling effect comparable with that observed in the Precordillera (section 6.3.2).
To the east, beneath the Precordillera (PC; 69°W), the data could indicate a 10-20 Ωm slab. In order to have equivalent conductances beneath PC (i.e., vertical integrated conductivity) with regard to the former inversion model, the algorithm had shortened the PC conductor vertically and shifted it to a shallower depth (from 35-45 km to 20-28 km depth; fig.9.7). Further to the east, beneath the Altipano, there is almost no difference between both model structures.
Both models (fig.9.7) can explain with equal fit the MT and tipper data. Only a slight difference in the Precordillera between the model responses of the TE-polarization mode data at period 100 s is observed (fig.9.8; 2-5° phase difference at 69°W).

Discussion of the models

It can be concluded that the MT data (fig.9.8) and the tipper functions (fig.9.9) are both insensitive to a possible conductive slab beneath the region near the coast. However, only measurements carried out off-shore could identify the presence or absence of a conductive slab, as has been demonstrated by Chave & Booker (pers. comm.).
In the Precordillera, on the other hand, the equivalent responses between the model with and without the conductive slab (fig.9.7, 69°W) do not allow its presence due to dehydration processes (i.e., a conductivity enhancement) beneath this region to be ruled out. Furthermore, the 3-D inductive effect increasing with period observed in the MT data (section 6.3.2), interpreted as a coupling between shallow 3-D local conductors and a conductive layer in depth (section 8), actually supports the 2-D model with the slab, where the TM mode data are more representative for two dimensionality.

9.2.2 2-D forward model: how deep and wide could the Precordillera conductor be?

The top depth of the Precordillera (PC) conductor traced in the previous inversion models (fig.9.7) was not properly determined due to the 3-D effect identified in the Precordillera (section 8), which was interpreted as a coupling between a shallow 3-D conductive anomaly and a deeper conductor. The magnetic distortion effect (which impeded the 2-D approach) was seen mostly in the TE-mode data (∼ N−S electric field component, the direction of the local azimuth), while the main information with regard to the shallow anomaly was seen in the tipper (or magnetic transfer) functions. Therefore a forward model was constructed to investigate two dimensionally the sensitivity of the TM-mode original data (i.e., WE electric field component) and the WE tipper component to the PC conductor.

The forward model (fig.9.10) was constructed by joining the ocean model (fig.9.1) in the west to the Altiplano (AP) conductor in the east. The latter was obtained from a MT inversion modeling with a reduced model grid (like in the ocean model); thus the AP conductor is here smoother as compared to the former inversion model (fig.9.7). The tested feature was the PC conductor at longitude 69°W embedded in a resistive space (200-2000 Ωm); its position and conductivity were varied systematically by trial and error. The top of the conductor was set to shallower depths with a conductivity of 3 Ωm between 2 and 10 km depth, embedded in a resisitive space (200 and 1000 Ωm). The depth range of this shallow conductive block was found from the WE tipper functions of the Precordillera, which was set fixed during the following sensitivity analysis (model "short"; fig.9.12). As a variable parameter, a deeper reaching block (6 Ωm) beneath the shallower conductor was incorporated into the model (f. ex., fig.9.14). Evidence of the fit improvement by the tipper functions with regard to the inversion model responses (in section 9.2.1) can be seen in fig.9.11 for the forward model response of the long PC conductor (fig.9.10). In the TM-mode phases, however, the fit between the forward model responses and the Ancorp data is not improved. A better fit is achieved with the Pica profile (fig.9.11; right).

Variation of depth

The following section discusses which features are most affecting the data. First, the bottom depth of the PC conductor was investigated, which is seen to be slightly sensitive for the TM-mode data, while the depth of its upper boundary is most reflected in the tipper functions.

Fig.9.12 shows the two extreme models regarding the depth of the conductor (10 km and 75 km depth), which gave the largest response differences. A PC conductor between these depths (or deeper than 75 km) responded closer to the *long* PC conductor (75 km deep) rather than to the *short* one (between 2 and 10 km depth; fig.9.12). The *short* PC conductor corresponds to the shortest possible model structure in the Precordillera which allows an acceptable fit with the data. Between PC and WC the TM-mode phases and tipper responses of the model with the *short* PC conductor fit better the data from the Pica profile at short period (68.5-69°W; fig.9.11). The fit of the long period data, in contrast, is slightly improved with the *long* PC conductor (75 km deep; fig.9.12) in this region. Between the coast and PC, the *long* PC conductor also better fits the tipper functions (69-70°W; fig.9.11), whereas the phases are insensitive to the depth of the conductor in this region.

It can be concluded that the PC conductor, with its top layer at $\sim$ 2 km depth, must exceed a depth of 15 km to explain the tipper functions and the TM-mode phases, especially for data from the Ancorp profile at long periods. With increasing depth of the lower edge, the model responses show little variation; the data at period $<$ 10000 s are fairly insensitive to a deeper ($>$75 km) structure.

Variation of width

The next feature to be varied is the width of the conductor, after fixing a mid-depth of 25 km for it (see above). Its western boundary should not be moved since this is definitely the best position to explain the data at this location, which means that the PC conductor in the

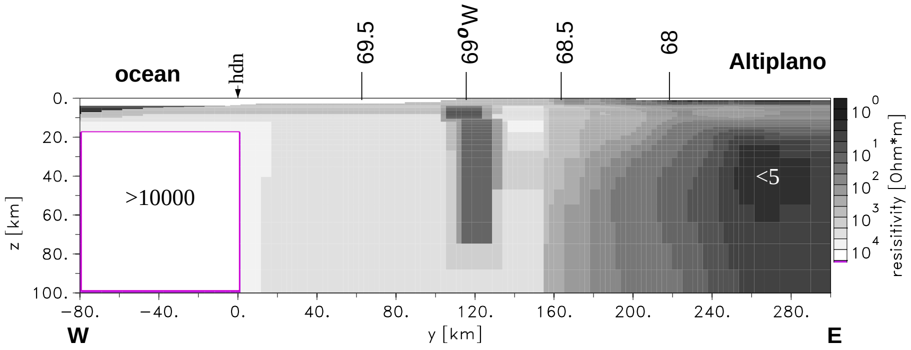

Figure 9.10: The forward model with the PC conductor (69°W) treated in the sensitivity analysis. The structures in the Altiplano (right of 68) correspond to the Ancorp inversion result for a homogeneous start model.

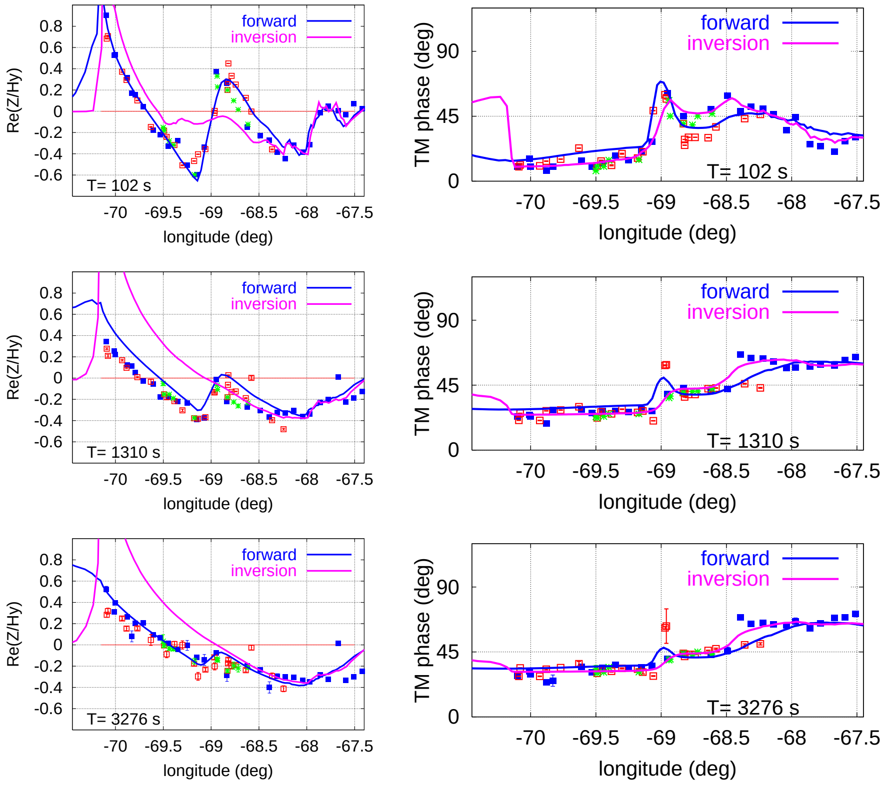

Figure 9.11: The lines are the responses of the MT Ancorp inversion model (*inversion*; fig.9.7) and the forward model (*forward*; fig.9.10). Different symbols are the data from the different profiles as explained in fig.9.2. From top to bottom are shown three different periods, representative for short, mid and long penetration depths (100, 1000, 3300 s). *Left:* Real parts of the WE component of the tipper function as function of site location (longitude). *Right:* TM-mode impedance phases.

west responds extremely sensitively to any edge variation. Analogous is the position of the eastern boundary of the shallow block (<10 km depth), which is well resolved due to good sensitivity. However, the eastern boundary of the block underneath (>10 km depth) is not well resolved especially for the data from the Ancorp profile. The Altiplano HCZ to the east apparently produces some effect confounding the information on the eastern extension of the

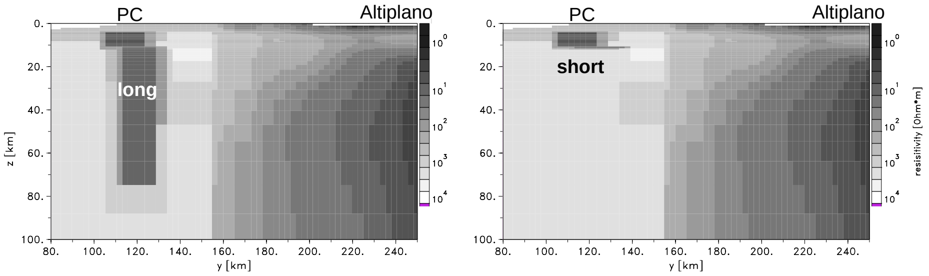

Figure 9.12: Two extreme models for investigating the sensitivity of the data to the extension in depth of the PC conductor (*long–short*). *Left:* The long conductor, further in depth is no more sensitive for the TM-mode data nor the WE magnetic transfer functions (MTF). *Right:* The short conductor, the less deep (10 km) possible for an acceptable fit with the WE MTF.

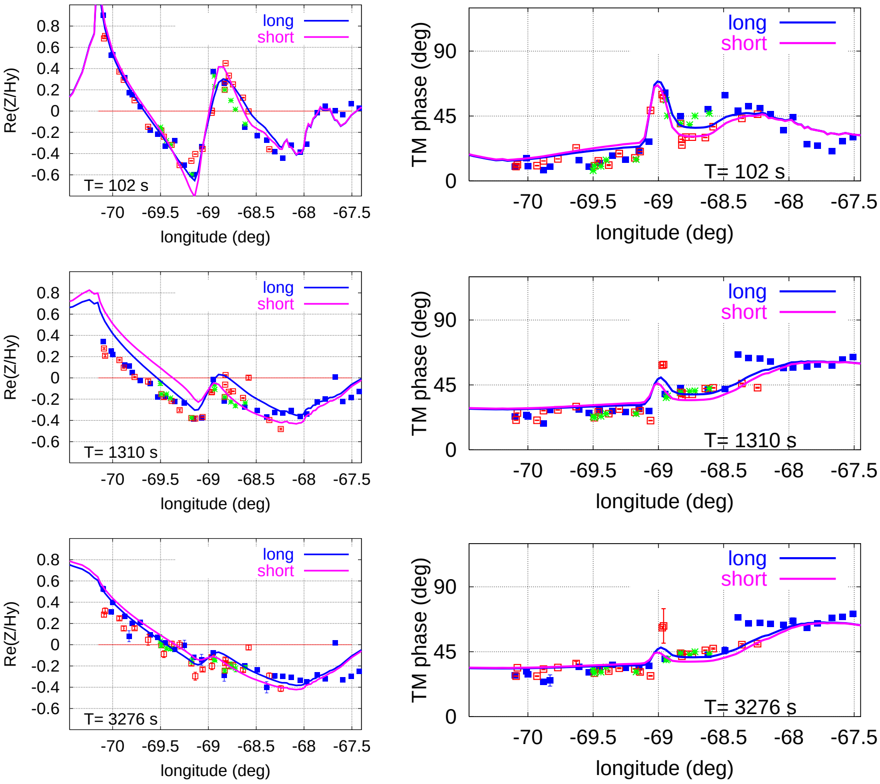

Figure 9.13: The lines are the responses of the model with the *long* and *short* PC conductors (fig.9.12). Different symbols are the data from the different profiles as explained in fig.9.2. From top to bottom are shown three different periods, representative for short, mid and long penetration depths (100, 1000, 3300 s). *Left:* Real parts of the WE component of the tipper function as function of site location (longitude). *Right:* TM-mode impedance phases.

deeper PC conductor. Therefore, a sensitivity analysis is performed to determine the eastern boundary of the PC conductor beneath 10 km depth.

The deeper conductor was extended to the east in the direction of the AP HCZ in order to test how differently from the original (narrower) PC conductor it responds. The extended eastern block (of 20-50 Ωm) is set between the depth of 30 and 40 km (fig.9.14). These depths are similar to the depth of the low seismic velocity layer (LVZ; 30-50 km depth) modeled by

Yuan et al. [2000] at these longitudes. It is worth mentioning that the responses of this model (fig.9.14) do not change much by extending the PC block (at 69°W) to a greater depth. Thus, the lowly resistive layer (20-50 Ωm) can also be connected with the Precordillera conductor (section 9.2.3).
The responses of the tipper function are insensitive to the horizontal extension of the conductor, while the TM-mode responses show some differences between PC and the Western Cordillera region (68-69°W; fig.9.15), especially for the data at short periods. The model with the extended conductive block connected with the Altiplano (fig.9.14) improves the fit with the Ancorp profile in this region, while the model with the vertical block separated from the AP HCZ better explains the data of the northern (Pica) profile.

9.2.3 Alternative models for Pica and Ancorp profiles

It can be concluded that if the Precordillera conductor was connected with the Altiplano conductivity anomaly at mid to lower crustal depths (model B; fig.9.14), such a structure is more suitable for the Ancorp profile (21°S), where fit with the TM-mode phases improves. In contrast, the PC conductor separated from the Altiplano one (A; fig.9.14) fits better with the northern profile (Pica at 20.5°S).
If the PC conductor extends further in depth (∼75 km), such a structure is more suitable for the Ancorp profile (fig.9.10), whereas a less deep conductor fits better with the Pica profile (model A; fig.9.14).
Combining the structures deduced from the sensitivity analysis, the preferred model for the Pica profile is model A (fig.9.16). Meanwhile, for the Ancorp profile, the preferred model is similar to model B, which considers the PC conductor to be connected with the AP one (fig.9.17). This model gives no change in response with the PC conductor between 25 km and 60 km depth.
The preferred model for the Ancorp profile was introduced in section 9.1.1 as the "complete" model to study the coupling effect between the ocean and the PC and AP conductors (responses in figs. 9.6, 9.5). The fit of the TM-mode phases is worse in the model responses which have a PC conductor deeper than 60 km (fig.9.18;69°). The WE tipper functions, in contrast, are insensitive to an extension of a deep block beyond 20 km depth.
The low resistivity layer (20-50 Ωm) between 30 and 60 km depth, assumed to be suitable for the Ancorp profile (21°S; fig. 9.17), comprises a low seismic velocity zone of 30-50 km depth modeled by Yuan et al. [2000] from receiver functions.

The following chapter (10) deals with the elaboration of a 3-D model of the whole region considering the results of this sensitivity analysis, i.e, the preferred models. Also, the TE-mode data, which are more sensitive to depth variations of the PC conductor and to NS changes, will be used for the 3-D modeling.

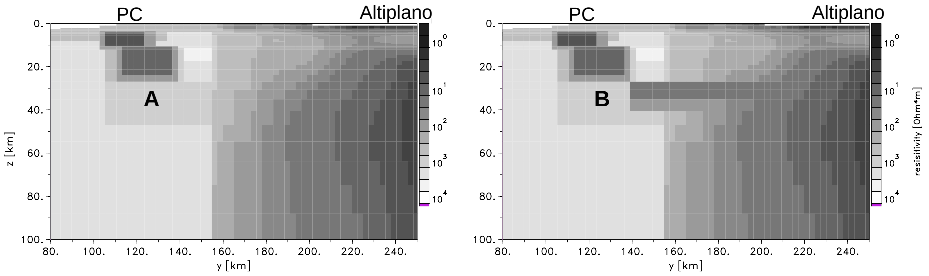

Figure 9.14: Two models for investigating the sensitivity of the data to the width of the PC conductor (5 Ωm) reaching 25 km depth. A sensitive response is observed in the TM-mode data. *A:* The PC conductor separated from the Altiplano (AP) anomaly (right of "pam") fits better with the Pica profile (20.5°S). *B:* The PC conductor connected by a 20 Ωm layer with the AP fits better with the Ancorp profile (21°S).

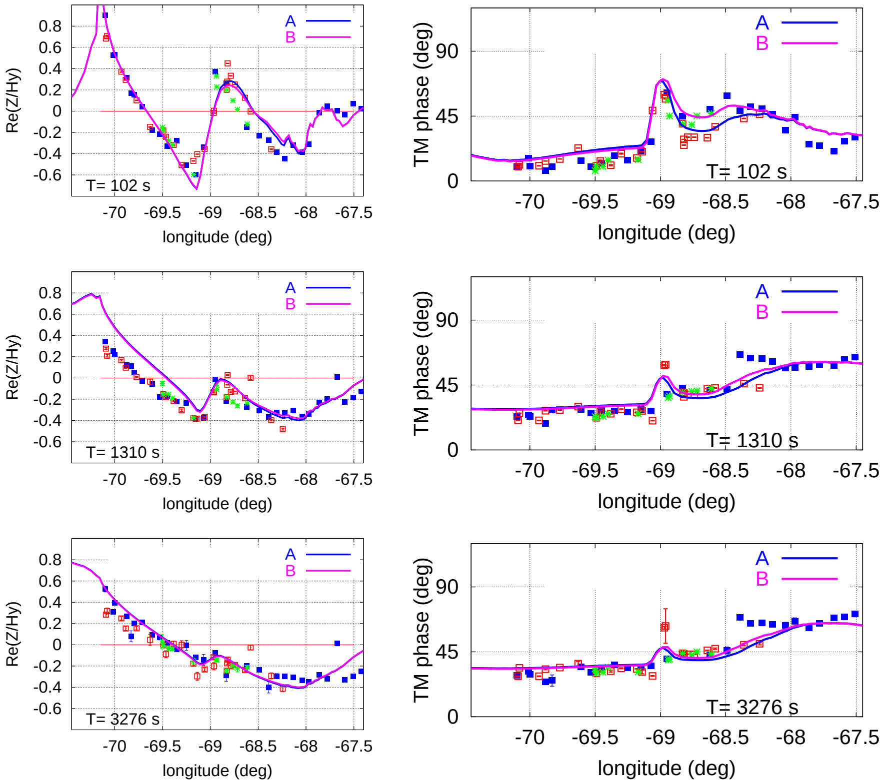

Figure 9.15: The lines are the responses of models A and B (fig.9.14). Different symbols are the data from the different profiles as explained in fig.9.2. From top to bottom are shown three different periods, representative for short, mid and long penetration depths (100, 1000, 3300 s). *Left:* Real parts of the WE component of the tipper function as function of site location (longitude). *Right:* TM-mode impedance phases.

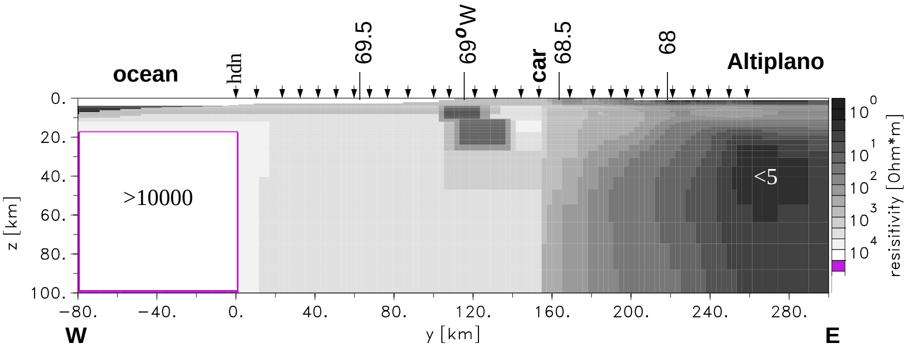

Figure 9.16: The preferred 2-D model for the *Pica* profile (20.5°S). The main conductivity structures are located in the Precordillera (69°W) and Altiplano. Site *car* indicated on top is used to compare responses (fig.9.18b) between this model and the model below.

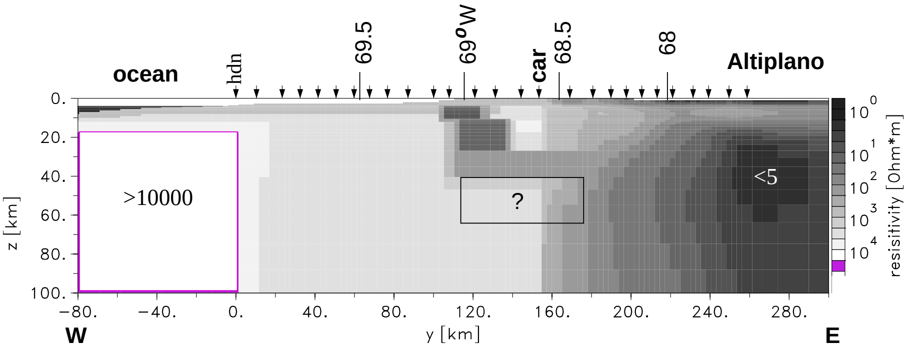

Figure 9.17: The preferred 2-D model for the *Ancorp* profile (21°S). The main structures are located in the PC (69°W) and Altiplano, which are connected with a 20Ω layer. The question mark inside the black rectangle indicates a possible vertical extension of the conductor down to a depth of 60 km (see text for explanation).

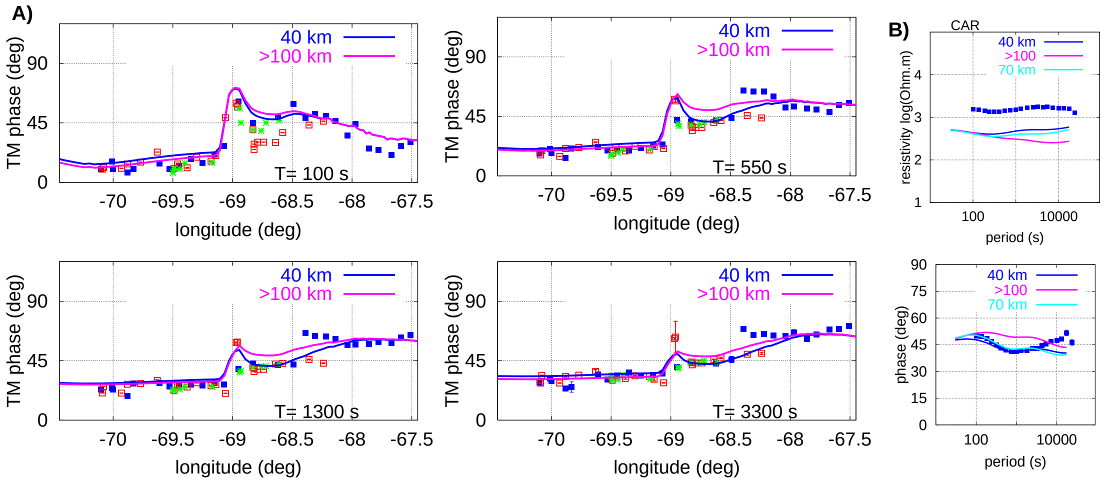

Figure 9.18: TM-mode phase responses (curves) of the preferred Ancorp 2-D model (in fig.9.17) for the bottom boundary of the PC-conductor (69°) at 40 km and >100 km depth: *A)* as a function of site location. Different symbols are the data from the different profiles as shown in fig.9.2. Four periods are shown (100, 550, 1300 and 3300 s). *B)*: TM-mode apparent resistivities (above) and phases (below) of site CAR from the Ancorp profile located at 68.5° (fig.9.17), above the conductive layer of variable depth (40, 50 and >100 km). The parallel shift by ρ_a between data and model curves reflects an electrostatic effect due to shallow heterogeneities.