7 SUMMARY AND OUTLOOK

7.1 Conclusions

Due to the lack of the additional geophysical, geological and petrological data, some of the problems discussed in Chapter 6 remain unresolved.

The most important question regards the depth to the slab beneath the forearc region south of 39°S where no constraining data are available. Also, the thin crust beneath the Longitudinal Valley, which can explain the observed positive Bouguer anomaly is not constrained. As shown in the Section 6.3.4 the measured gravity high can also be reproduced by dense masses within the crust. With no additional information, this ambiguous result can not be solved by density modelling alone. Another issue is the nature of the uppermost forearc mantle in the northern segment (36-39°S) where an unidentified body exists at the bottom of the accretionary wedge.

Based on the three-dimensional density model and its analysis, the following conclusions can be drawn:

A. Deep vs. shallow slab

As shown in Figures 6.19 and 6.20, the measured gravity field is well reproduced south of 38.8°S, by a shallow oceanic plate when the accretionary prism has a lower density (2.8 Mg/m^3) than in the northern Arauco-Lonquimay segment. However, there may be a difference between the bulk density in the Valdivia and the more southern Bahía Mansa-Osorno segment as an increase in higher density metabasites is observed south of the Valdivia region. However, rocks formed at the plate interface at depths of 30–35 km are observed on the surface in the Valdivia region, implying a denser accretionary prism (2.85 Mg/m^3) according to the density model. However, this does not necessarily mean that the slab is currently in the same position as at the time these rocks were formed (Glodny, pers. comm.).

Within the northern Arauco-Lonquimay segment, the structure of the accretionary prism is more complicated, with a dense mafic lower crust expected beneath the Nahuelbuta granitoids (section 5.4.1). Interestingly, an increase in surficial metasediments suggests that a less dense accretionary wedge is possible.

However, as shown in Figures 6.21 and 6.22, a density lower than 2.85 Mg/m^3 within the accretionary prism is, from the density modelling point of view, impossible. Hence, no along-strike density variation has been included within the forearc accretionary prism, not only in order to maintain the simplicity of the model, but also because estimating the composition of the accretionary wedge at greater depths is impossible. It is assumed that the accretionary wedge consists of one layer of almost constant density from the surface to the oceanic plate, but there is no control on the proportion of low density metasediments and high density rocks at depth (Glodny, pers. comm., 2004). With no other geophysical data to constrain the deeper structure of the accretionary prism, the following, based on the forward density modelling technique, is concluded:

The gravity data do not suggest a low density accretionary wedge in the northern Arauco-Lonquimay segment, as is assumed from geological observations. The slab position here is well constrained by the seismic data and thus a low density accretionary prism can not be compensated by a shallower oceanic plate. In the Valdivia and Bahía Mansa-Osorno segments, where there are no seismic data available, and hence there is no control on slab position and forearc density structure, a low density accretionary wedge can be modelled if a shallower slab compensates the mass deficit. Therefore, the major differences in shape and magnitude of the Bouguer gravity anomaly along the coastline is controlled and influenced by the density, and hence composition of the accretionary wedge. In turn, this determines the position of the oceanic plate. Thus, if the accretionary wedge is dense, the oceanic plate is deeper and if the wedge is less dense then the plate is shallower.

B. Thin vs. thick and dense crust

As interpreted by Echtler (pers. comm. 2002), one possible source of the observed gravity high in the southern Bahía-Mansa segment is the crustal thinning beneath the Longitudinal Valley. However, another possible explanation is a dense crust of normal thickness (~40 km) beneath the Longitudinal Valley (Section 6.3.4). Due to the lack of constraining geophysical data, the curvature technique was used in attempt to determine which of these two different possibilities is most likely. Several curvature methods were applied to the modelled gravity (Section 6.4) and compared to the curvature results obtained by applying the same methods to the measured data. The model with crustal thinning below the Longitudinal Valley was found to better reproduce most of the curvature attributes that were tested.

However, this result does not fully resolve the question of crustal thinning in the forearc region south of 40°S. Without additional geophysical data, it will remain an open question.

C. Serpentinized mantle vs. crustal material

The origin of the unidentified body cannot be resolved using gravity data, despite the constraining seismic results. From a gravity prospectives, the unidentified body could represent serpentinized/hydrated mantle as well as mafic lower crustal accumulates.

In order to match the observed gravity data, the unidentified body in the density model exceeds the size of the same body in the local earthquake tomography model. The continental Moho predicted from the local earthquake tomography model interpretation would meet the subducting plate at ~40 km depth, whereas in the density model this point would be some 10–15 km shallower. The crustal seismicity, based on the ISSA earthquake catalogue (Bruhn, 2003), occurs to depths of 50 km (Figure A.3); but is more concentrated in the upper layer of the unidentified body, where in the local earthquake tomography model it is imaged as crust. Hence, it is also more logical to interpret the unidentified body in the density model as being crustal material. Further indications that the upper part of the unidentified body could be crustal material is seen in the results and interpretation from the SPOC wide angle reflection/refraction seismic profiles, where the observed and interpreted intersection of the continental Moho is at 30–40 km depth. As shown in Figure 6.1 (B,C), along the two middle and south SPOC profiles, the upper limit of the unidentified body in the density model exceeds the interpreted continental Moho, and is situated in a layer with P-wave velocities of 7.0 km/s.

The above observations of the unidentified forearc body coupled with the shape of this body in the 3D density model leads to the conclusion that the unidentified body may consist of both crustal material, in the upper layer, and serpentinized mantle in the lower. A mafic composition for lower crustal rocks could be related to the intruded granitoids of the Nahuelbuta Mountains. This granitoids represent the subduction-related magmatic arc and a mafic lower crust at its base would be expected.

However, an argument against the unidentified body consisting of serpentinized mantle in its lower part is the depth of the seismogenic zone, which, based on the ISSA earthquake catalogue, as already mentioned, reaches as far as 50 km depth. If the unidentified body was serpentinite, a reduction in seismicity would be expected. However, seismicity in this region is not really reduced and thrust earthquakes also occur in the zone of the contact of the slab with the presumed serpentinite. This situation is unlikely. The down-dip limit of the subduction thrust earthquakes is suggested to be controlled by the formation of serpentinite in the forearc mantle (Peacock and Hyndman, 1999 and references therein). Further, the hypocentre of the great Valdivia earthquake of 1960, relocated according to the SPOC results, would overlap with the low velocity serpentinized zone.

To distinguish serpentinite from the crustal material, the P- and S- wave velocity structures, as well as Poisson's ratio, must be further investigated (Kamiya and Kobayashi, 2000). Serpentinite has low velocities and high Poisson's ratio, therefore to use a P- wave velocity model only, may not be sufficient for detecting serpentinite. Nor can the density modelling solve this problem, due to its ambiguity.

7.2 Outlook

The study area in the Southern Andes at 36–42°S will remain the subject of further geological and geophysical investigations in the framework of the TIPTEQ (The Incoming Plate to mega-Thrust EarthQuake processes) project. This project comprises several German institutions and their South American partners and is focused on studying the processes of the subduction zone along the convergent margin in South Chile. The investigations should improve knowledge of the subduction-related structures and processes, particularly related to the seismic activity within a subduction zone.

Given the ongoing focus on this region, the results of the work presented in this thesis lead to some suggested improvements for the near future.

In order to have a better control of the gravity field along the margin, more gravity data should be collected. The critical area is the offshore-onshore transition, especially in the area south of 40°S where there is a lack of the ship-borne gravity data. There is also a gap in the database in the onshore forearc between 36°–37°S where there are no gravity stations between the coast and volcanic arc. Also, additional gravity measurements in the forearc between 37°–39°S, would improve the already existing onshore gravity database. At these latitudes, the measured stations are not controlled by new remeasurements (hence there is no control on the quality of these data) and some smaller gaps occur in the Coastal Cordillera. However, the area between 36–39°S is geophysically well controlled. Hence, new gravity stations would complement the other geophysical constraints that already exist.

An improvement for the further gravity modelling would come from the results of the GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) mission, expected to launch in 2006 (Rummel et al., 2002). The GOCE mission will measure high-accuracy gravity gradients and provide global models of the Earth's gravity field and of the geoid. The gravity gradients can be modelled in IGMAS simultaneously with the gravity anomaly. This would allow a better control of the modelled structures. Also, the GOCE mission aims at an accuracy of the gravity anomaly in the range of 1×10^{-5}m/s^2, which is better than the accuracy estimated for the existing gravity database. To include GOCE results would, therefore, be very useful in the case of the density model for South Chile because the existing gravity database is not homogeneous.

Apart from the gravity data, the area south of 39°S is fully unconstrained by other geophysical data. To resolve the open problems related to the position of the slab and the continental crustal structures overlying the slab, geophysical measurements (active or passive seismic measurements) are necessary. Also, answering the question of the existence of serpentinized mantle under the forearc in the northern segment of the study area, which is also relevant for understanding seismic activity, requires additional geophysical methods and/or measurements.

The 3D model can be also used to investigate the lithospheric structure in terms of isostasy. In addition to topographic loads, IGMAS allows direct calculation of loads within the lithosphere (A.4). The combined internal and topographic loads can then be used to better estimate the flexural rigidity and the isostatic compensation of the continental plate. Recently, a new method for estimating elastic thickness (thin plate approximation) has been developed by Wienecke (pers. comm., 2004) using the convolution method of Braitenberg et al. (2002). The Moho predicted from the density model will be used in the near future as an important constraint for this method.