1. Introduction

This thesis discusses the Cenozoic development of the eastern Andean backarc of southern Bolivia, including the Subandean Belt to the west and the Chaco Basin to the east. The Chaco Basin is a mostly flat and largely undeformed region west of the Central Andean orogen and is therefore geographically described as Chaco Plain (e.g. Horton and DeCelles, 1997; Echavarria et al., 2003). Geologically, the Chaco Basin forms the present retroarc foreland basin of the Central Andes in southern Bolivia. An ancient foreland basin attaches eastward that underwent deformation since the Miocene and appears at present in the east-vergent fold-thrust belt of the Subandean Belt (e.g. DeCelles and Horton, 2003; Echavarria et al., 2003; McQuarrie et al., 2005). The present position of the deformation front represents the boundary between the Subandean Belt and the Chaco Basin (e.g. Dunn et al., 1995; Fig. 1.1).

Retroarc foreland systems form through the flexural deflection of the lithosphere in response to loading by thickened crust, attributed to continental collision (e.g. Beaumont, 1981; Jordan, 1981; Sinclair and Allen, 1992; DeCelles and Gilles, 1996; Catuneanu et al., 1999). Loading by orogens leads to the partitioning of foreland systems into flexural provinces, i.e. foredeep, forebulge, and back-bulge (DeCelles and Gilles, 1996; Catuneanu et al., 1999). The sedimentary fill of the foreland basins records the interaction between thrust loading, isostatic adjustments of the continental lithosphere, as well as bending moments, eustasy, and surface processes that redistribute material from the mountain belt into the adjacent basins (Sinclair, 1997). The interplay of base level changes and sediment supply controls the degree in which the available accommodation is consumed by sedimentation (Miall, 1997). This defines underfilled, filled, and overfilled stages in the evolution of a foreland basin system, in which the depositional processes are dominated by deep marine, shallow marine, or fluvial sedimentation, respectively (Sinclair and Allen, 1992).

Numerical models exist to simulate the growth of thrust wedge foreland basins systems, and attempt to evaluate the significant individual parameters and how they interact (e.g. Jordan, 1981; Stockmal and Beaumont, 1987; Flemings and Jordan, 1989; Sinclair et al., 1991). However, natural examples such as the Andes and their adjacent eastern foreland basins are not as homogenous along strike as predicted by synthetic orogen modeling (Flemings and Jordan, 1989; Flemings and Jordan, 1990). Heterogeneities occur with respect to the mechanical properties of the crust (Waschbusch and Royden, 1992), the tectonic, geologic, geomorphic setting, and the stratigraphic evolutions of the basin fill (Jordan, 1981; Jordan and Flemings, 1991). Preexisting structural elements may also modify the flexure of the foreland plate and hence the depositional pattern (Bachmann and Müller, 1992; Gupta and Allen, 2000). However, most orogen-foreland basins are expected to present mixtures of such end-members and thus the relative importance of either tectonically driven or erosionally driven uplift may be interpreted from the depositional style and stratigraphic architecture of the foreland.

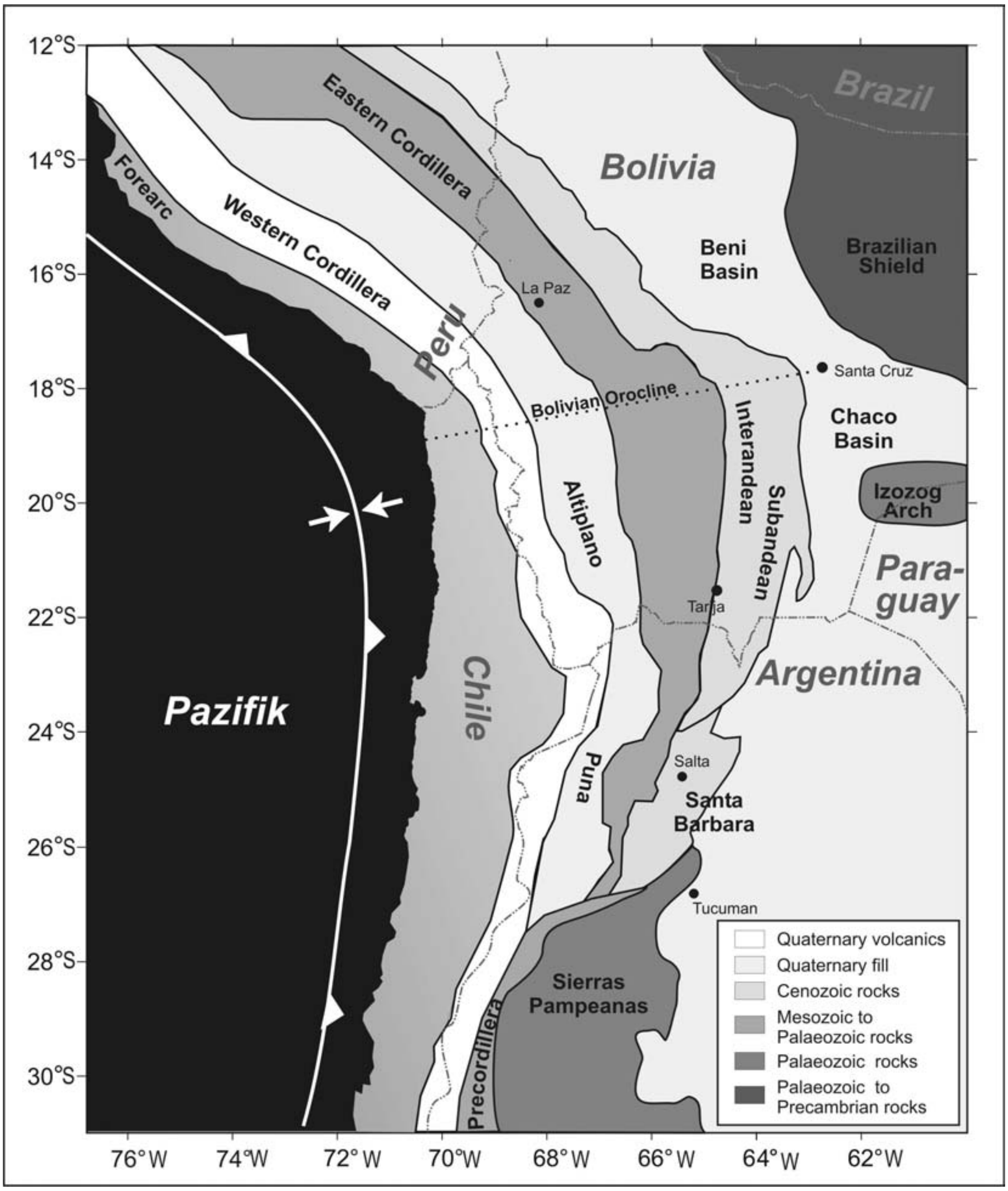

Fig. 1.1: Morphostructural classification of the Central Andes (after Scheuber and Reutter, 1992), illustrating the geological units and the setting of the Chaco Basin. Dashed lines represent national borders; dotted line marks the axis of symmetry of the Bolivian Orocline.

1.1 General geological setting

The study area is located along the eastern margin of the Central Andes in southern Bolivia (Fig. 1.1). The approximately 7500 km long Andes represent a part of the circum-Pacific active continental margin system. Oceanic lithosphere of the Pacific Ocean was subducted since the Jurassic (Coira, 1982; Scheuber and Reutter, 1992), and the Andean orogen was built on the overriding South American continental lithospheric plate since early Oligocene (Sempere et al., 1990; Gubbles et al, 1995; Jordan at al., 1997). The orogenic development is mainly due to tectonic shortening and subordinate magmatic addition within the upper lithosphere (e.g. James, 1971; Roeder, 1988; Sheffels, 1990; Kley, 1993; Schmitz, 1994).

The Central Andean orogen extends between 12° and 32° S with an east-west width of approximately 400 km in the northern and southern Andes, and 800 km in the Central Andes, respectively (between ~18° S and ~23° S; see Fig. 1.1). A significant characteristic of the

Central Andes is the elbow of the Bolivian Orocline (Fig. 1.1) in which the coastline as well as the strike of the orogen changes from NW-SE towards N-S (e.g. Carey, 1958; Isacks, 1988; Kley, 1999). In the following, we focus the study on the eastern backarc of the Central Andes.

1.1.1 Structural style of the Central Andes between ~18° and ~23° S

Fig. 1.2 shows the present large-scale structure of the Central Andes along a profile at 21° S latitude (after Scheuber and Giese, 1999). From west to east, the following tectonic units exist: the forearc, the arc, and the backarc.

The forearc at ~21° S (Fig. 1.2) can be differentiated after Günther (2001) and Muñoz and Charrier (1996) from W to E in the Coastal Cordillera (representing a Jurassic magmatic arc), the Longitudinal Valley (Cretaceous magmatic arc and western foreland of the Andean Plateau with an average elevation of 1600 m), and the Chilean Precordillera (predominantly Paleozoic and Mesozoic rocks).

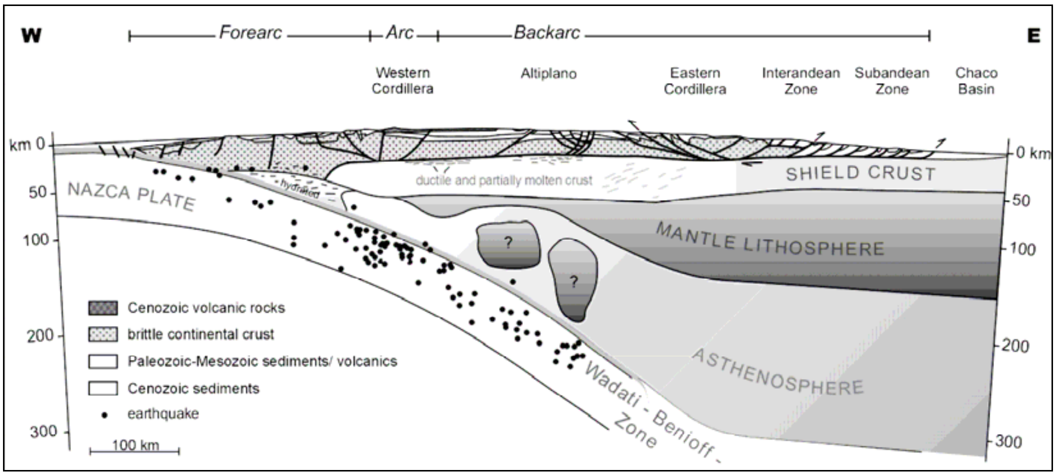

Fig. 1.2: Schematic profile through the Central Andes at 21° S based on geological and geophysical interpretation (after Scheuber and Giese, 1999; Ege, 2004).

The Western Cordillera (Fig. 1.2) is built by the Neogene to Recent magmatic arc with peak elevations of up to 6000 m, formed by Pliocene to Quaternary volcanoes (Günther, 2001).

The southern Bolivian backarc of the Central Andes is composed (from west to east) of the Altiplano, the Eastern Cordillera, the Interandean and Subandean Belts, and the Chaco foreland basin. The Altiplano plateau with mean heights of 3600–4000 m (Fig. 1.2) represents a complex intramontane basin and is characterized by a 4-10 km thick Cenozoic continental sedimentary fill and a largely flat topography (e.g. Welsink et al., 1995; Baby et al., 1997; Rochat et al., 1999). Peak elevations of the Eastern Cordillera reach up to 6000 m. The bivergent, thick-skinned Eastern Cordillera mainly involves Precambrian to Ordovician basement (Kley, 1996; Müller et al., 2002). East of the Eastern Cordillera, the topography drops to the Interandean Zone, a 2000-3000 m high, east-vergent thrust belt, composed of basement structures (Kley, 1996). The adjacent thin-skinned Subandean Belt forms a classical, east-vergent foreland fold-thrust belt, which grades eastward in the active retroarc foreland basin, the Chaco Basin (Dunn et al., 1995).
The Chaco foreland basin grades near the symmetry axis of the Bolivian orocline into the Beni foreland basin of central Bolivia (Fig. 1.1; Hinsch, 2001). To the northeast, it borders the Precambrian Brazilian Shield (Fig. 1.1). To the east, the northern Chaco basin onlaps against the Paleozoic Izozog arch whereas the southern part of the Chaco Basin grades into a

continental foreland (Fig. 1.1). In the south, the Subandean-Chaco basin terminates against the Santa Barbara System of Argentina (Echavarria et al., 2003; Fig. 1.1).

1.2 Objectives of this study

The objective of this study is to determine and describe timing and properties of the Cenozoic development of the eastern backarc of the Central Andes. Because timing and style of Andean orogenic growth and shortening is reflected in the sedimentary record of the Cenozoic basin fill, its depositional ages, lithology and facies, provenance, thickness variations, and will yield information not only about the evolution of the recent foreland basin but may also indicate the development of the adjacent Andean orogen.

We approached these objectives by combining various fields related to sedimentary geology:

- **Sedimentary petrology**: sandstone classification, uplift and erosion of provenance areas through time
- **Lithostratigraphy**: characterization of distinct formations, their depositional environment, sediment transport modes, paleocurrent patterns, and climate indicators
- **Biostratigraphy**: paleontological study of microfossils from the Yecua Formation north of 20° S, ecology of the Yecua wetland, depositional age of the marine Yecua facies
- **Isotope geochemistry**: determination of the Yecua wetland water composition ($^{87}Sr/^{86}Sr$-ratio, $\delta^{18}O$ - and $\delta^{13}C$-values)
- **Geochronology**: Ar-Ar age dating, palynology, and paleontology to determine the depositional ages of the Cenozoic formations
- **Subsurface study**: 2D-industrial seismic interpretation and well log analysis, yielding subsidence patterns in the northern Chaco and 2D numerical models at 21.5° S

1.3 Database

The study area extends between the axis of the Bolivian Orocline near Santa Cruz (~18° S) and the Bolivia-Argentina border near Yacuiba (~22.5° S) along the Subandean-Chaco foreland basin toward the Bolivian-Paraguayan border in the east.

Due to a gap in the seismic coverage available to us between 20° and 21° S, we defined two regions of study. The southern region, Area I, ranges from the Bolivia-Argentina border in the south to 20.5° S in the north. The northern region, Area II, encompasses the area between the Bolivian orocline (~18° S) and Boyuibe (20.5°S). Fig. 1.4A illustrates the setting of Area I and Area II (also see Appendix A).

We were made available 66 2D-reflection seismic profiles and 34 well logs, courtesy of YPFB and Chaco S.A., both situated in Santa Cruz. Of those, 29 seismic sections and 13 well logs (Fig. 1.4B) are presented in the Appendices F and G. Seismic profiles and well log data south of 20.5° S are presented in the thesis of Cornelius Uba (2005).

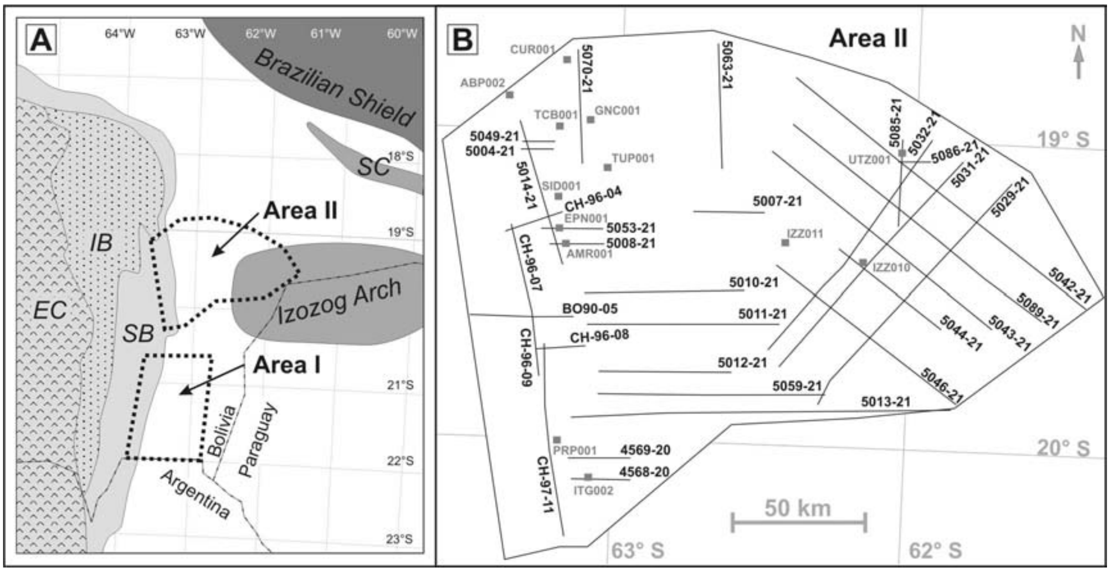

Fig. 1.4: Basemap of the study area, showing (A) the setting of Area I and Area II (modified after Suárez-Soruco, 2000) and (B) the location of the 29 seismic sections and 13 well logs from Area II.

During two field seasons in 2002 and 2003, my colleague Cornelius Uba and I studied 45 stratigraphic sections. Outcrops are generally limited to the transition between the Chaco Basin and the Subandean Belt. Detailed descriptions of those sections recorded north of 21.5° S (No. 1-31, Fig. 1.5) are shown in Appendix A, with selected outcrop photographs in Appendix B. Detailed descriptions of those section recorded south of 21.5° S are documented in Uba (2005).

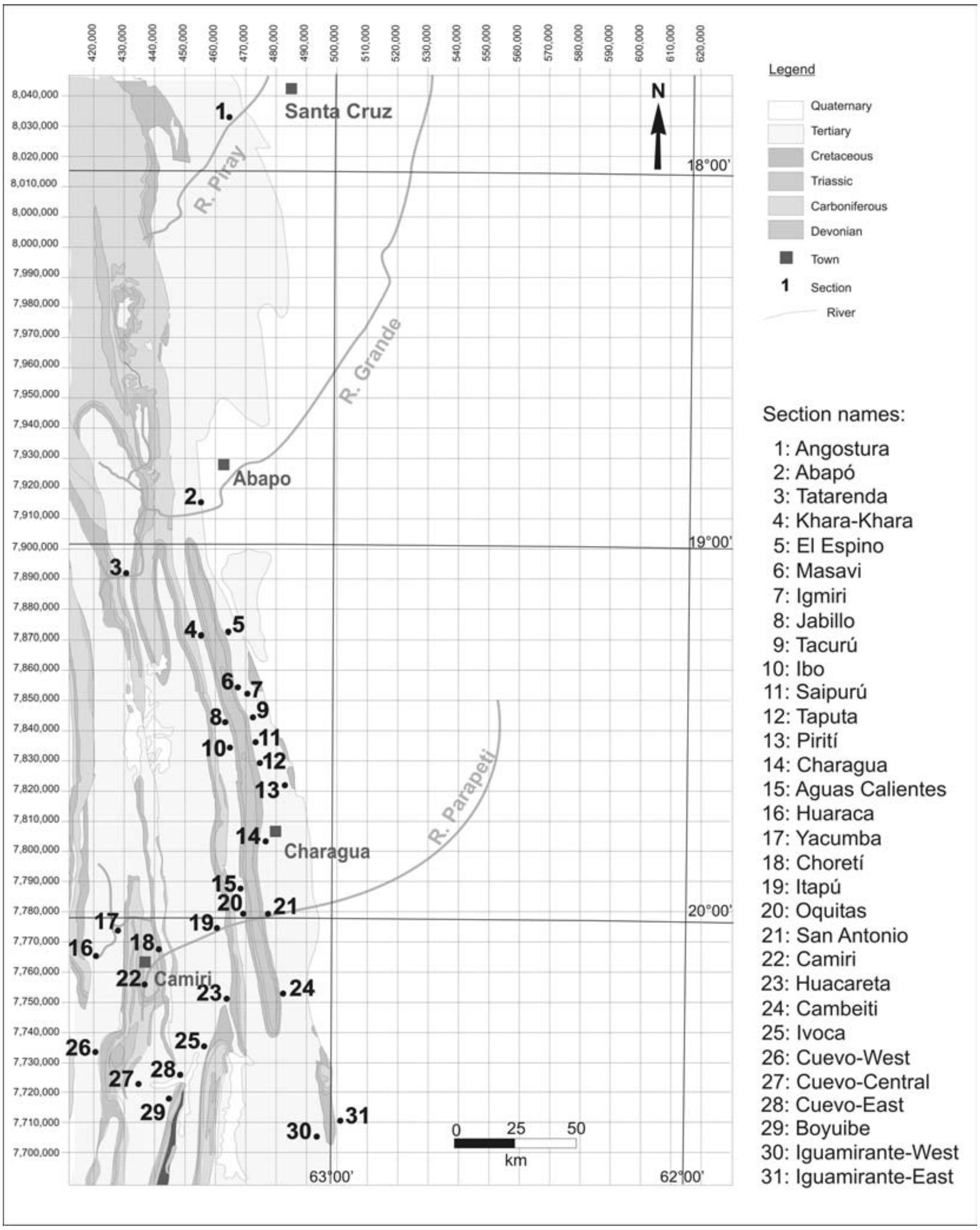

Fig. 1.5: Geological map of Area II (modified after Suarez-Soruco, 2001), showing the location of the studied sections.

Samples and thin sections are archived at the Freie Universität Berlin, Department of Geological Sciences, Malteserstrasse 74-100, 12249 Berlin, Germany.