2 The CINCA'95 experiment

In 1995, the interdisciplinary CINCA project was carried out to investigate the structure and evolution of the continental margin of Northern Chile. It was a combined onshore-offshore experiment which includes active and passive seismic experiments as well as other geophysical investigations like the acquisition of bathymetric or gravimetric data (Hinz *et al.*, 1995). The feasibility to study an active erosive convergent margin enabled to get information about convergence parameters such as mass transfer, pattern of seismicity, upper plate deformation and kinematics (e.g. von Huene & Scholl, 1991; Isacks, 1988). These parameters, but also the determination of the geometry and the physical properties of the plate interface were subject of the investigations with the aim to get hints for a better understanding of the evolution of the convergence system (e.g. Jordan *et al.*, 1983; Jensen *et al.*, 1984; Tebbens & Cande, 1997; Yanez *et al.*, 2002).

In this chapter a brief introduction to the geological and tectonic setting resulting from further investigations is given as well as an overview of the investigation area including a description of the marine seismic experiments.

2.1 Geological and tectonic setting

The coast of Northern Chile is dominated landward by the Andes with a height up to 7000 m. In contrast, offshore Chile, the Peru-Chile trench dominates the ocean bottom with a depth down to 8000 m. It is an active continental margin where the oceanic Nazca plate subducts below the South American continent with an average velocity between 80 - 90 mm/a (DeMets *et al.*, 1990; Clift & Vannucchi, 2004). The age of the currently subducting oceanic crust is about 50 Ma (e.g. Clift & Vannucchi, 2004). From further observations it is well known that the mode of mass transfer is tectonically erosive rather than accretionary within the investigation area (e.g. von Huene & Scholl, 1991).

The incoming lithosphere is young, thin and buoyant along the Peru-Chile trench. This indicates that the subduction angles are shallow offshore Northern Chile (e.g.

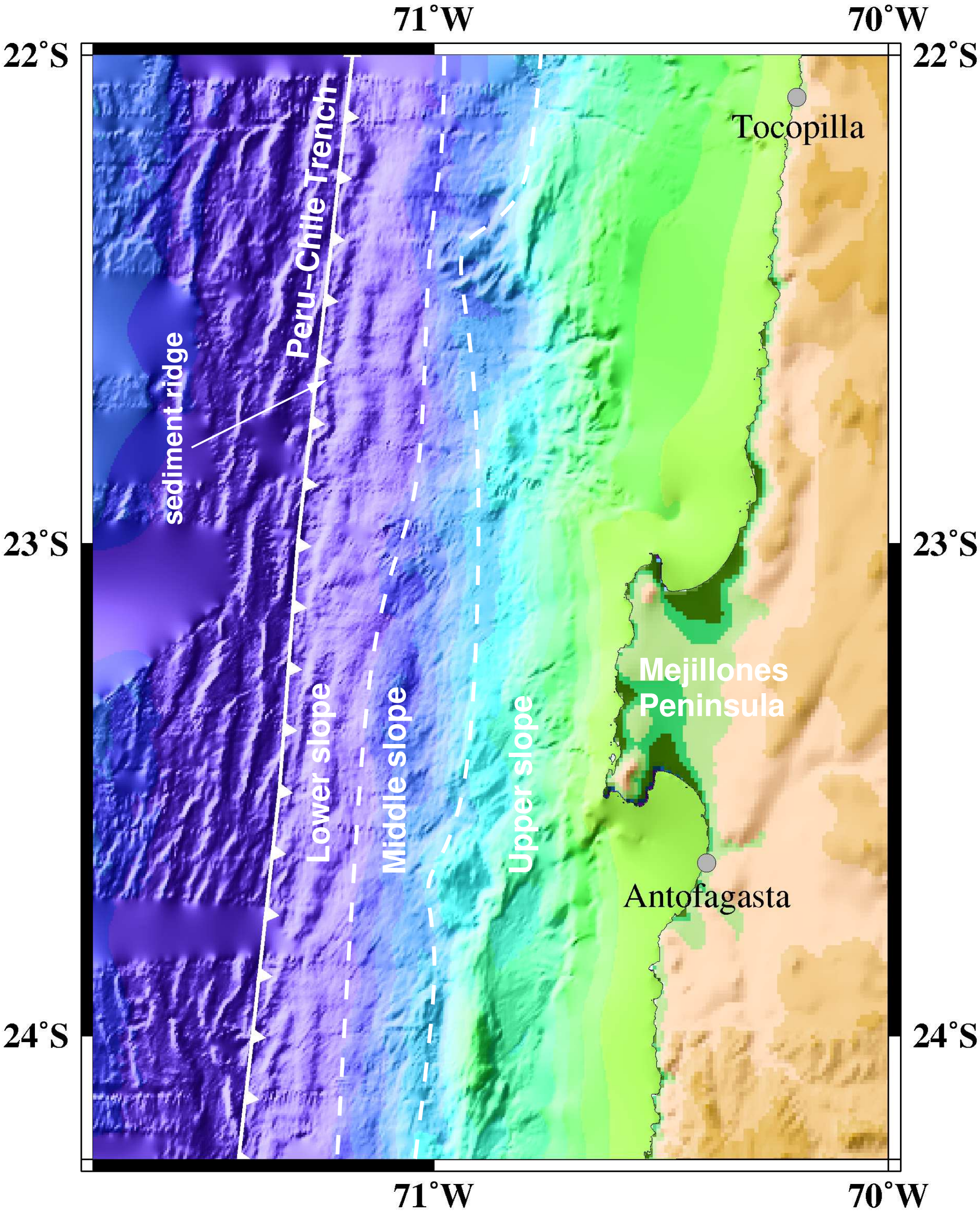


Figure 2.1: Bathymetric image of the west coast of Northern Chile between 22°S and 24°S according to von Huene et al. *(1999).*

Jarrard, 1986; Stern, 2002; Clift & Vannucchi, 2004). In the Central Andes, basal as well as frontal tectonic erosion occur at the trench where the latter resulted in an eastward migration of the volcanic front of about 200 km since the Jurassic (Rutland, 1971; Scheuber *et al.*, 1994). This means that the present forearc crust in the Central Andes was the magmatic arc in Jurassic and early Cretaceous times and the original crust was replaced to a large extent by plutonic and volcanic rocks (Scheuber *et al.*, 1994). These rocks are responsible for high seismic velocities observed during further studies of wide-angle seismic data (e.g. Patzwahl, 1998; Lüth, 2000).

2.1.1 The Nazca plate

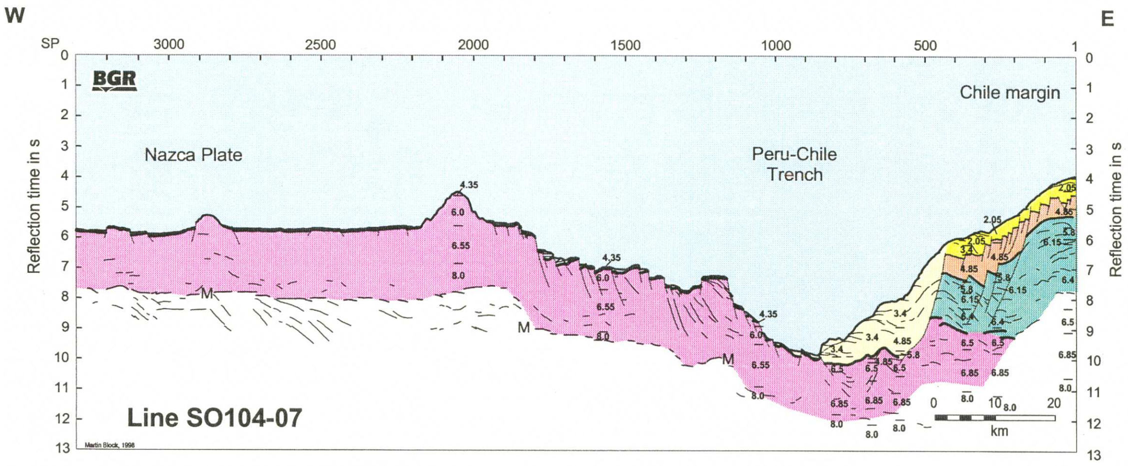
The ocean bottom off Northern Chile is nearly devoid of sediments. Only a thin cover of pelagic sediments is present (< 300 m; Hinz *et al.*, 1995). The bathymetry of the area between 22°S and 24°S (Figure 2.1; von Huene *et al.*, 1999), also acquired during the CINCA project in 1995, illustrates the ocean bottom formations. In Figure 2.1, the Peru-Chile trench is marked by the white line with triangles. First ocean bottom structures are located at about 50 km west of the trench whereas further seaward, the ocean bottom morphology is more or less smooth. The seafloor roughness and the distinctiveness of the observable structures within the bathymetry (Figure 2.1) increase towards the trench. Differences in altitude up to 1000 m have been observed while the mean value is about 500 m (e.g. Patzwahl, 1998). A first idea of the vertical dimension of the ocean bottom morphology was given by means of line drawings within time-sections (Hinz *et al.*, 1995) from line SO104-07 (Figure 2.2(a)) and line SO104-13 (Figure 2.2(b)) but, however, the real proportions of the structures are not identified within these figures. Here, the oceanic Moho ('M') is situated at about 2 s two-way-travel time below the seafloor. This value can be associated with a Moho depth of about 6 km - 7 km.

2.1.2 The trench region

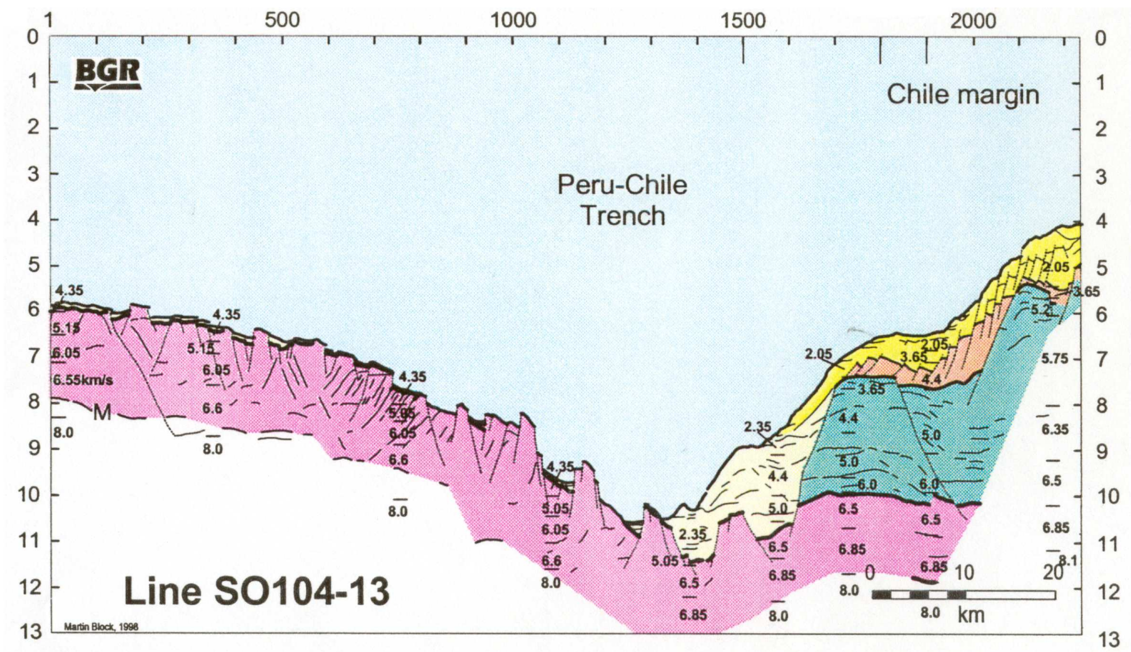
Due to the extremely arid climate in the Central Andes and the existence of inland basins that reduce the supply of sediments to the slope (Hartley & Chong, 2002) the trench axis is empty of a turbidite sequence (e.g. Kulm *et al.*, 1977). Directly at the trench a sedimentary ridge is situated which forms the deformation front extending nearly parallel to the Peru-Chile trench (see Figure 2.1; von Huene *et al.*, 1999). It is part of a frontal prism composed of more or less stratified detritus from the continental slope (e.g. von Huene *et al.*, 1999). A continuation of the ocean bottom structures below the lower slope is also indicated within the line drawings (Figure 2.2).

2.1.3 The outer forearc region

Hinz *et al.* (1995) and von Huene *et al.* (1999) separated the outer forearc into three parts: the lower, the middle and the upper continental slope. Both the boundary between lower and middle slope and that between middle and upper slope are depicted by dashed white lines in Figure 2.1 according to von Huene *et al.* (1999). Four main seismic units were identified within the outer forearc (Hinz *et al.* (1995)) where the beige area in Figure 2.2 marks the sedimentary frontal wedge unit at the lower continental slope. The other units of the middle slope, from top to bottom,



(a) Interpreted time section of line SO104-07.



(b) Interpreted time section of line SO104-13.

Figure 2.2: Line drawings for interpretation of line SO104-07 (a) and of line SO104-13 (b). The color scale indicates the different seismic units and 'M' marks the Moho. Also included are the seismic velocities obtained from wide-angle seismics.

are (cf. Hinz *et al.*, 1995): seismic unit CM1 (yellow area in Figure 2.2) which contains semi-consolidated siltstones and sandstones; seismic units CM2 (orange colored area) and CM3 (green colored area in Figure 2.2) composed of metamorphic rocks whereas CM2 additionally contains rocks of sedimentary, extrusive and intrusive origin. The red area in Figure 2.2 marks the oceanic crust. Landward rotated listric fault systems characterize the subsurface of the middle continental slope.

2.2 Experiments within the investigation area

In the framework of the Collaborative Research Center (SFB 267), seismic and other geophysical investigations in Northern Chile were carried out onshore and offshore in the last decade to provide clearer images of the subsurface of the Chilean continental margin. Besides the active seismic experiments, a seismological network was installed to study the local seismicity (e.g. Husen, 1999).

The active seismic investigations in Northern Chile were subdivided into three main parts working with different techniques. Wide-angle/refraction seismics was carried out during the PISCO (Proyecto de Investigación Sismológica de la Cordillera Occidental) project in 1994 (Lessel, 1998; Schmitz *et al.*, 1999) but also within the CINCA'95 (Hinz *et al.*, 1995) and ANCORP'96 (Andean Continental Research Program; ANCORP working group, 1999; Lüth, 2000) projects to fill the gap between offshore and onshore measurements. Two deep reflection seismic profiles were acquired and analyzed: the PRECORP profile in 1995 (Yoon *et al.*, 2003; Yoon, 2004) and the ANCORP profile in 1996 (e.g. ANCORP working group, 2003; Buske *et al.*, 2002; Yoon, 2004; thick blue lines in Figure 2.3). The results from these two experiments as well as the wide-angle results acquired at the same latitudes enabled to build a nearly complete depth image across the subduction zone in the investigation area (e.g. Sick *et al.*, 2005). Not only seismic experiments took place during the field campaign of the CINCA experiment but it comprised also magnetic, gravimetric and geothermal measurements as well as the acquisition of the bathymetry (see Hinz *et al.*, 1995).

The investigations presented here are restricted to the marine reflection seismic data, acquired during the CINCA experiment (Figure 2.3)), which are introduced in the following section.

2.2.1 The marine seismic reflection experiments

The CINCA study area extends laterally between 19°S and 26°S with the seaward part extending to approximately 75°W longitude. It comprises the deep Peru-Chile trench and the continental slope as well as seaward adjacent parts of the Nazca plate. During the experiment, about 4500 km of marine reflection data (Figure 2.3), 1300 km of wide-angle/refraction data and 460 km of onshore wide-angle seismic data were acquired. In addition to the streamer lines, the airgun shots were recorded by several onshore stations.

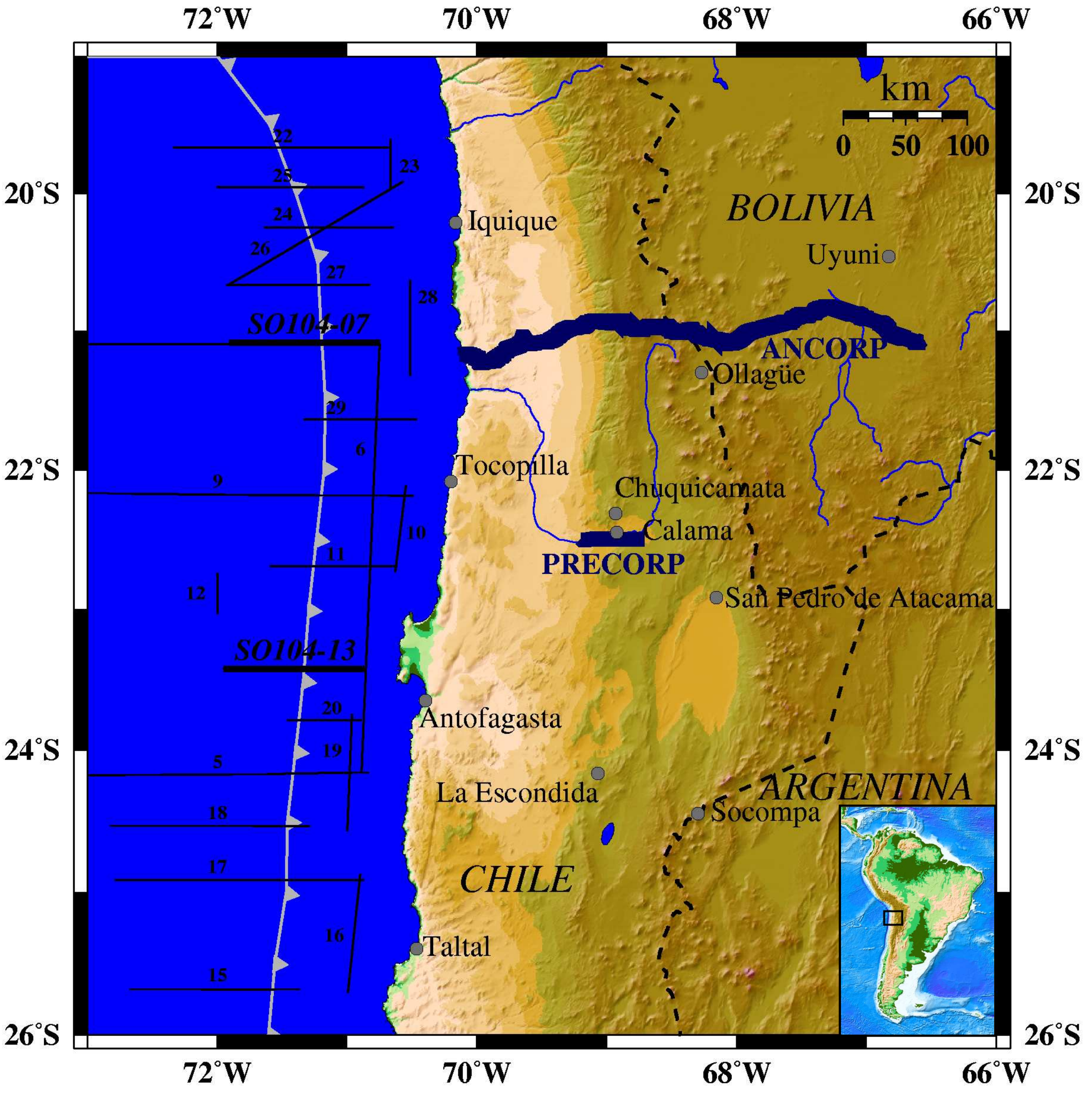


Figure 2.3: Overview of the CINCA area. The solid black lines located offshore denote all airgun profiles acquired during the CINCA experiment, whereas the thick solid black lines mark profiles SO104-07 and SO104-13. The trench is depicted by the grey line with triangles. The thick dark blue lines at about 21° S and 22.5° S show the locations of the deep reflection experiments ANCORP and PRECORP, respectively.

During the active seismic part of the CINCA experiment, 22 seismic reflection profiles were acquired by the research vessel "SONNE"(solid black lines in Figure 2.3). In this thesis, two profiles are processed and discussed: Line SO104-07 at about 21°S and line SO104-13 at 23.25°S (thick black lines). Both are oriented approximately perpendicular to the trench which is depicted by the grey line with triangles in Figure 2.3. The profile length of line SO104-07 was 120 km and that of line SO104-13 was about 110 km.