Chapter 2

2. Receiver Function Central Andes Project

The Receiver Function Central Andes (ReFuCA) project was a seismological study carried out along two different profiles at 21°S and 25.5°S where the stations were operated for a period of almost 2 years between 2002 and 2004. The project involved collaboration between scientist from Germany, Argentina, Bolivia and Chile within the collaborative research program "Deformation Processes in the Andes" SFB-267 (SonderForschungsBereich-267). The intention was to record teleseismic waves ***(P and S)***, for use of teleseismic tomography method.

2.1. Instrument deployment and data processing

During the last funding period of the SFB-267 program, in cooperation with GFZ-Potsdam and with the collaboration of our South American partners, a set of 59 seismological stations was deployed and operated (March 2002 - January 2004) at 21°S along a profile between the Coast of Chile at ~70°W and the western margin of the Interandean Zone system in Bolivia at ~64.5°W (see Figure 2.1). Instruments used for this experiment consisted of 47 short-period (SP) RefTek (Refraction Technology dataloggers) and EDL (Earth Data Logger) units equipped with 1-Hz Mark L4-3D seismometers and 9 SAM (Storage and Acquisition Module) with broadband (BB) Guralp CMG-3ESP seismometers *(see Appendix A.1. – Table 1 for details)*. The station spacing was about 10 km (Figure 2.1).

The events (at epicentral distances between 30° and 95°) used in this work are listed in the Appendix A.2. A total of ~500 GB of data were acquired and stored in the GEOFON Data Center[1]. Digital *P-waveforms* from 154 teleseismic events and 31 *S-waveforms* with *Mw* ≥ 5 were obtained from PDE[2] catalogue. These events were located predominantly along the western coast of Central and North America and the Atlantic ridge. The ray coverage is generally well distributed but towards Antarctica the events are clearly less well represented (Figure 2.2).

In addition, a set of 19 stations was deployed at ~25.5°S and operated between July 2002 and January 2004 in a profile ~200 km long (Figure 2.1). The instruments used in this case were 10 short-period EDL units with 1-Hz Mark L4-3D seismometer and 9 SAM with BB Guralp CMG-3ESP seismometers *(Appendix A.1. - Table 2).* The spacing between stations was about 10-15 km. A complete list of the events detected by this profile (≥30°≥95°) is presented in the Appendix A.2. Digital *P-waveforms* from 177 teleseismic events and 29 *S-waveforms* with *Mw* ≥ 5 were also obtained from PDE catalogue and ~250 GB data were stored at GEOFON data center.

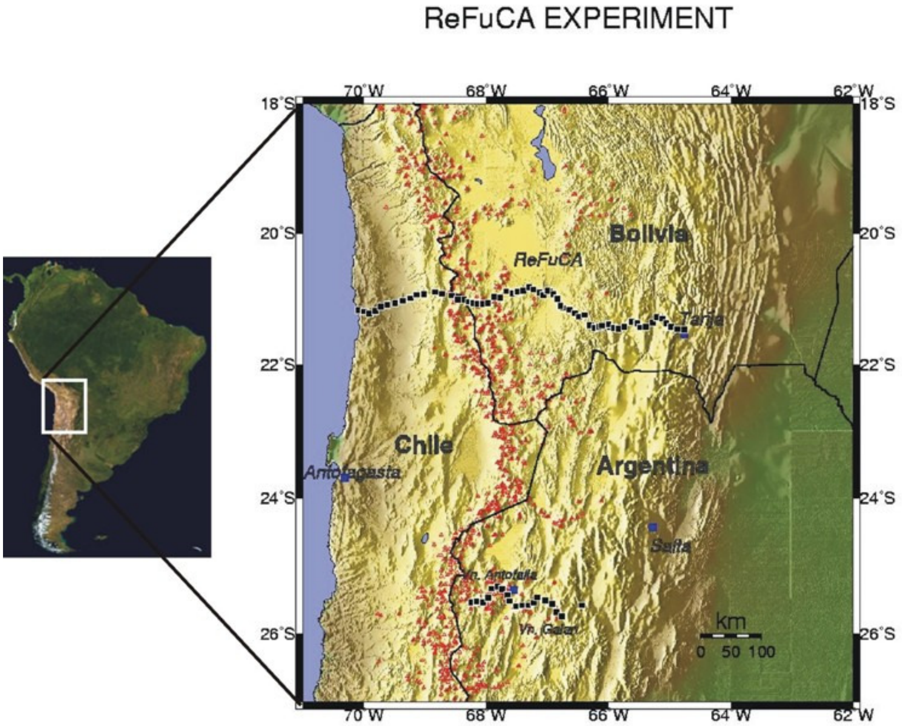

Figure 2.1: Location of the 21°S (RF) profile between the coast of Chile and the city of Tarija in Bolivia and the 25.5°S (PC) profile in the Argentine Puna. The southern profile is in the area of Antofalla and Galan volcanoes.

For both profiles, all stations were run with external hard-drives according to the instruments: 4-6 GB **Earth Data L**ogger and **SAM** and 20 GB **RefTek** (only in Bolivia and Chile). Timing was synchronized at each station using Global Positioning System *(GPS)* receivers and the sampling rate for the SP stations was 100sps and 50sps for the BB stations. Power supply was provided by solar panels, one in case of short-period stations (50 watt) and two for broadband stations (100 watt). The power supply was stored by batteries attached to a regulator that controlled the energy provided to the instruments (Figure 5). All the instruments were provided by the Geophysical Instrument Pool Potsdam (GIPP-GFZ).

All raw data (~800 GB) has been processed, converted to MiniSEED format and stored at the *GEOFON.* Online requests to *GEOFON* were made in order to access the data that were afterwards converted from MiniSEED to Q-File format. This format was needed to use the SHM (Seismic Handler Motif from Stammler, 1992) program for picking the *P*- and *S- waves* first arrivals for the different components. For teleseismic tomography we used seismic waves generated at epicentral distances between 30° and 95° (Figure 2.2). At epicentral distances of less than 30° triplications occur in the crust and upper mantle boundary resulting in complication on P- and S- wave arrivals. At distances greater than 95°the phases become complicate due to interactions with the earths core (Walck, 1984).

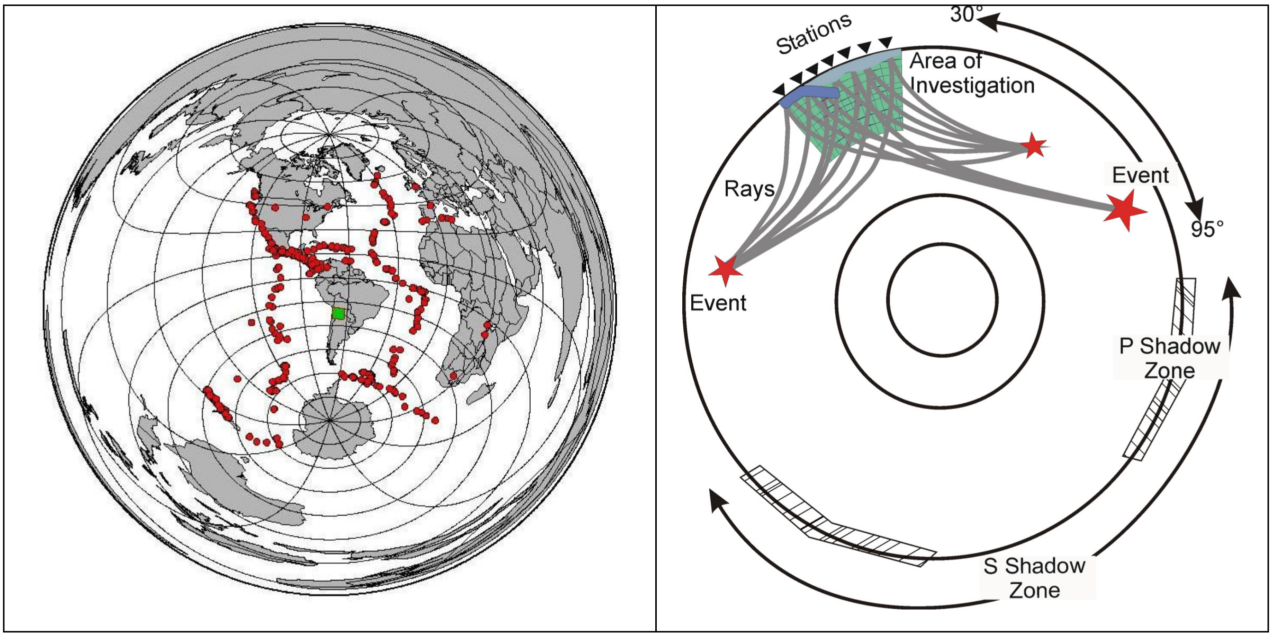

Figure 2.2: (Left) distribution of teleseismic events (red dots) used in this study for both seismological profiles between 2002 and 2004. Events that provided teleseismic arrivals for P- and S- phases are plotted together for epicentral distances between 30° and 95°. Note the inhomogeneous distribution of events from north and south and the more homogeneous distribution between east and the west of our study area (green square in the centre of South America). (Right) Cartoon showing the principle of teleseismic tomography; the area of investigation (green) with superimposed grid and ray tracing from three hypothetical events; P- and S- shadow zones also displayed.

Restitution of ground displacement was made for broadband and short-period signals separately. After restitution all traces had been filtered using pass band 1-3s 2nd order filter. SAM stations have showed, in some cases, a time delay that has been induced by a Firmware module problem. This time error was found to be 0.975 milliseconds (Güralp *pers. com.*), hence a data correction was possible. In those cases where the error proved bigger than the amount previously indicated, the data was not included in the analysis (Figures 2.3 and 2.4).

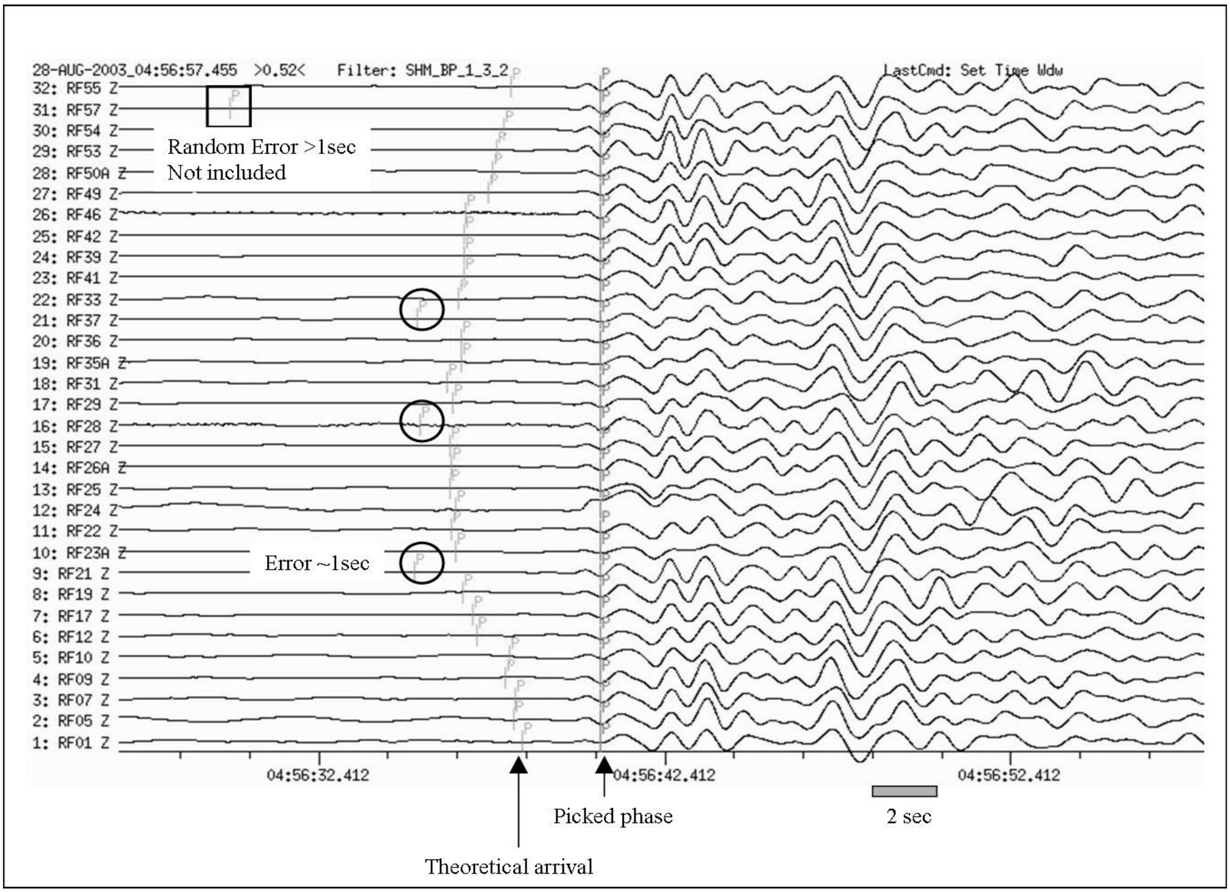

Figure 2.3: SHM screen showing an example of the vertical component (Z) of P waveforms from one event aligned by picked times after restitution and filtering for Altiplano profile at 21°S. The black circles include some of the P-wave delays detected during data processing due to the failure of the Firmware module (Güralp pers. com.). The square on the upper trace encloses the random error of the arrival of the phase probably related to poor GPS coverage (this type of data was excluded from analysis).

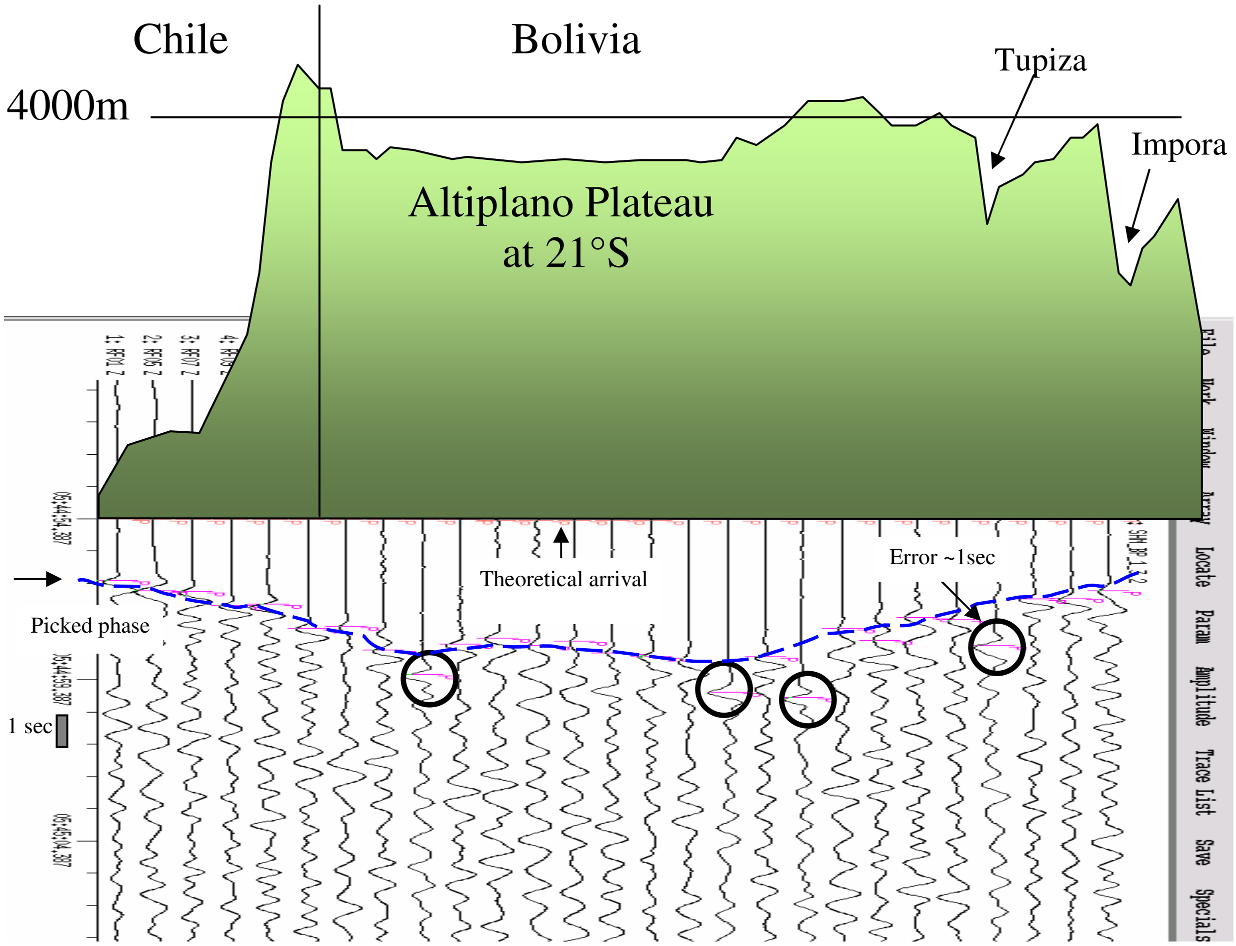

Figure 2.4: Superimposed topography related to arrival times for the Z component of P-waves showing greater delays beneath the Altiplano, where the Andes reach their greatest altitudes. Circles denote errors in real arrivals due to a Firmaware module failure. The effect of topography was corrected later (Moho and station corrections, see Chapter 3).

2.2. Installing the stations

Deploying a seismic station in the field is often not an easy task. Usually, the literature does not deal with the problems that accompany deploying stations for longer periods of time. Our experience after almost 2 years of field work is that there are specific aspects that must be considered if a project is to be concluded successfully, since a proper installation will provide better quality data for analysis. Some of the issues encountered during this project are as follows.

- In the Central Andes, the irregular topography makes the environmental conditions very harsh. Temperatures can reach 30° C or more during the day and fall to 20° below zero during the night. A 50° C difference may therefore affect the proper functioning of the instruments if they are not installed properly. Digging holes for this purpose, up to 1 meter depth for the recording system and seismometers, helped to maintain the temperature variations within an acceptable range. In addition, the boxes that contained the equipment were provided with an extra layer of thermal isolator. Some equipment included a temperature regulator but the same precautions were always done. The batteries attached to the equipment were especially affected by decreases in temperature. It was therefore necessary to prevent this by covering the batteries with a small amount of soil.

- Strong winds may produce two undesired effects on the equipment: one is the noise (sometimes related to a deficient installation) and the other one is the fact that strong winds can alter the position of the solar panels or in some cases, cover the panels with a layer of sand. By setting the panels at a proper inclination for collecting solar energy, one may allow to be exposed to winds that can reach up to 140 km/hour in the Central Andes.

- Hard disks are sometimes prepared or sealed and recommended for use up to 9000 feet (~3000 meter). In our case, some hard disks presented problems after one year's work, so they needed to be replaced. The stations that presented this problem were those deployed above the recommended altitude above sea level. An extra number of hard disks for replacement were therefore always included in the list of field trips material.

- For the Altiplano and Puna plateaus, precipitation in form of rain and snow can normally alter the functioning of the equipment by covering the solar panels or destabilizing the position of the seismometer. With snow the problem is more dramatic as it can close the access roads for weeks or even months at a time. Special care was taken for stations that were deployed in those areas and all of them were provided them with larger hard disks, as well as digging channels for run off. We also built a well consolidated plate of concrete for the seismometer, as it may become destabilized because of the effect of precipitation.

- The presence of animals can also be a critical point. Leaving cables exposed was also avoided during the deployment.

The stations were visited periodically (i.e. 3-4 months) to avoid data loss due to hardware or software failures, strong climatic changes, etc., that affected the proper functioning of the equipment. Data quality was controlled and a backup was made in the field. These and other factors can vary if the work is carried out near a populated area (which is not the case of the Altiplano and Puna plateaus) but again the noise induced by human activity will alter the recording and quality of the data. A cartoon showing an example of the arrangement of the instruments at one station is presented as example in Figure 2.5.

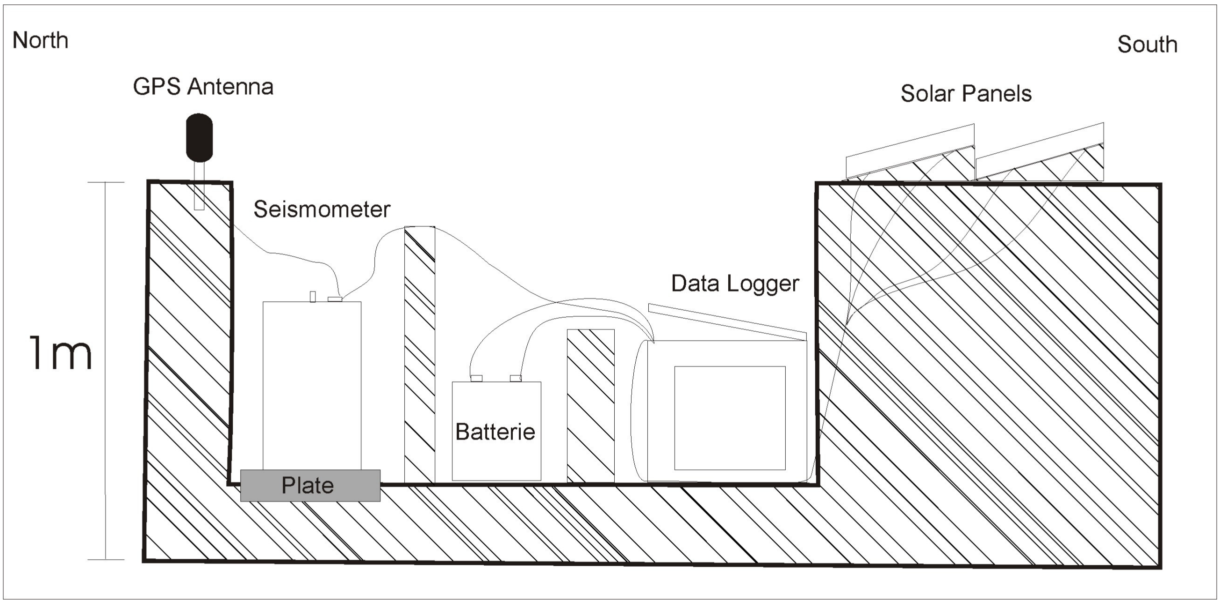

Figure 2.5: Cross section of one of our broadband stations. Solar panels inclined towards to the equator. The plate that supports the sensor was previously consolidated and is made of concrete. At least ~30 cm soil covers the instruments after installation. Superficial drainage channel for runoff has not been included here but supposes to envelope the deployment in plain view.

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[1] *GEOFON is a permanent network with ~40 globally-distributed stations that permits access to seismological data via the internet to persons and institutions all over the world.*

[2] *Preliminary Determinations of Epicenters (PDE) online catalogue http://neic.usgs.gov/neis/epic/ from the National Earthquake Information Center (NEIC) that determine location and size of all destructive earthquakes worldwide*