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Basement Depth in the Paraná Basin with High Frequency Receiver Functions

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Abstract

We present preliminary estimates of basement depth and basalt thickness beneath two seismic stations in the Paraná basin using the teleseismic receiver function method. Deep earthquakes in the nearby Andean subduction zone are a good source of high frequency (up to ~10Hz) P waves suitable to study the main layers of deep sedimentary basins. Beneath Presidente Prudente the basement depth (about 4.5 - 4.9 km) is not well defined but the total basalt thickness is clearly defined as 1. 2km; beneath Três Irmãos, the basement depth is 3.8 km and the basalt thickness is 0.5 km. These values are consistent with isopach maps of the Paraná basin and show that teleseismic receiver functions are potentially very useful to investigate deep sedimentary basins in Brazil.

Introduction

Seismological methods have been extensively developed to extract information about the receiver structure beneath a seismic station from the records of distant earthquakes, called Receiver Function (RF) method (e.g., Langston, 1979; Ammon, 1991; Wilson & Aster, 2002), and have been successfully used for deep crustal studies worldwide (e.g., Zandt & Ammon, 1995). Crustal studies in the Paraná basin using RF (Assumpção et al., 2002; França & Assumpção, 2003) show a series of shallow reverberations and conversions due to the sedimentary pack beneath the station. For deep crustal studies with RF, frequencies lower than about 1 Hz are commonly used. Much higher frequencies can be used to study shallow layers. The Paraná basin is conveniently located near the Nazca plate subduction zone, where the high frequency P waves from intermediate and deep earthquakes are not much attenuated since the propagation path avoids the asthenospheric wedge above the subduction zone, and the asthenosphere beneath the South American stable platform is not much developed.

Basement depth in the Paraná basin has not been mapped in detail as relatively few oil exploration wells have been drilled deep enough (Fig. 1). Most wells drilled for ground water do not reach the crystalline basement. More accurate knowledge of basement depth will be necessary not only for tectonic studies, but also for other purposes such as ground water management which is

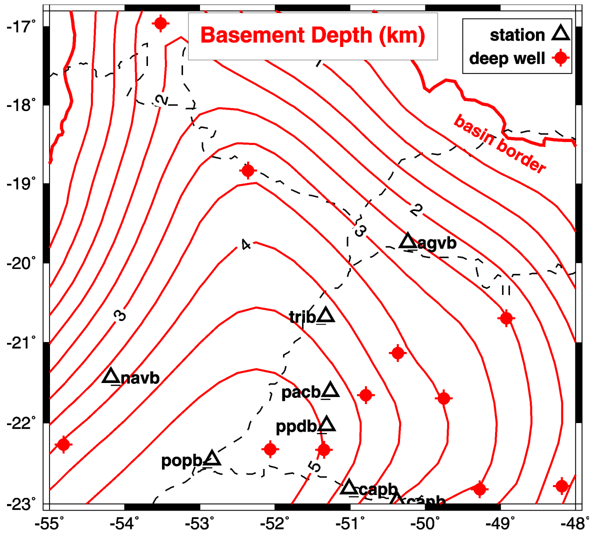

Fig. 1. Basement depths in the Paraná basin based on deep wells from Paulipetro and Petrobrás. Triangles are seismic stations. This paper shows results for stations *ppdb* (P. Prudente) and *trib* (Três Irmãos).

Figura 1. Profundidade do embasamento na Bacia do Paraná baseado em furos de sondagens da Paulipetro e Petrobrás ("deep wells") que atingiram o embasamento. Triângulos são estações sismográficas. Apresentam-se aqui os resultados das estações ppdb (P.Prudente) e trib (Três Irmãos).

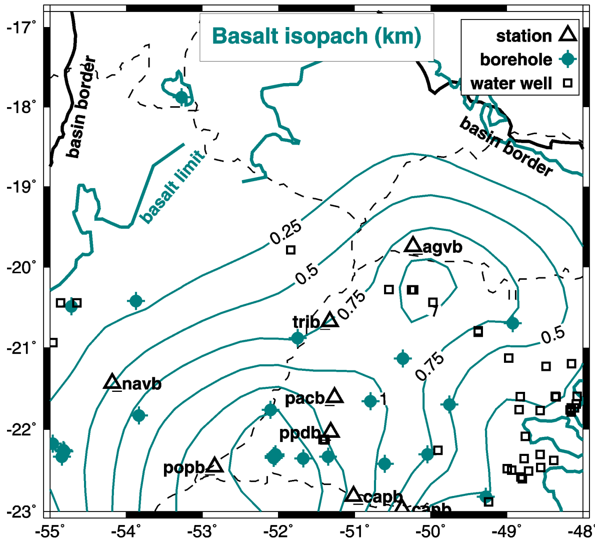

Fig. 2. Total basalt thickness (Serra Geral Formation) based on wells drilled for oil (Petrobrás and Paulipetro) and water (Yamabe, 1999).

Figura 2. Espessura total do basalto (Fm. Serra Geral) na Bacia do Paraná baseado em furos de sondagens em poços de petróleo (Paulipetro e Petrobrás) e poços de água (Yamabe, 1999).

expected to become increasingly more important. Here we present analysis of high frequency receiver functions at two seismic stations to determine the thickness of the basalt layer (Serra Geral Formation) and the depth to the crystalline basement. We show that high frequency receiver function is a powerful tool to investigate the properties of the main layers in intracratonic basins in Brazil.

Receiver Function

The recorded seismic waveform of a distant earthquake includes information about the source, path through the mantle and local structure under the station. The deconvolution operation (dividing the radial by the vertical component) removes almost all effects from the source and propagation path in the mantle. The time-domain trace of this transfer function, called the “receiver function” (RF for short), contains essentially all the P- to S-wave conversions, and reverberations at interfaces with S-wave velocity contrasts (e.g., Langston, 1979; Ammon, 1991; Wilson & Aster, 2003). Fig. 3 shows the ray diagram for the converted Ps and the multiple PpPms phases from one interface. This technique has been successfully used to study crustal and upper mantle discontinuities (e.g., Meijde et al., 2003; Wilson & Aster, 2003). The near surface low-velocity layers in a sedimentary basin affect the shape of the receiver functions but are usually modelled as a single average layer in studies of the deep crust (e.g., Assumpção et al., 2002; Meijde et al., 2003). Detailed information of the sedimentary layers, such as obtained by Julià et. al. (2004), are rarely a target for receiver function analysis. This is because the high frequencies necessary to sample thin layers are more susceptible to scattering from small scale lateral structure variations, and the usually low signal-to-noise ratio at frequencies above ~4Hz for teleseismic distances.

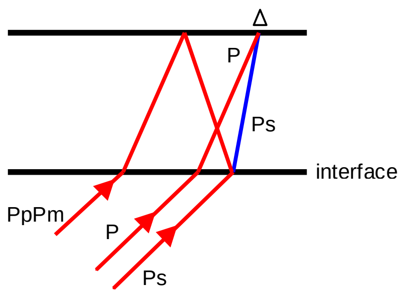

Fig. 3. Ray diagram for the direct P wave, Ps conversion and PpPms multiple. Red lines are P wave, blue is S wave.
Fig. 3. Raios das fases P direta, conversão Ps, e múltipla PpPms. Linhas vermelhas são ondas P e azul onda S.

We calculated RFs for two stations in the Paraná basin (*ppdb* and *trib*, in Figs 1 and 2) using the time domain deconvolution technique (Ligorría and Ammon, 1999) with frequencies up to ~10 Hz. We used earthquakes with epicentral distances in the range 11^o to 60^o and magnitudes m_b>4.5. The RFs were inverted by the linearized method of Herrmann & Ammon (2002) using an initial model with several constant-velocity layers with 0.2 km thickness near the surface and 0.5 km at larger depths. In the inversion, Vp/Vs ratio was fixed and densities were calculated from the seismic velocities. Receiver functions for several different events are inverted simultaneously.

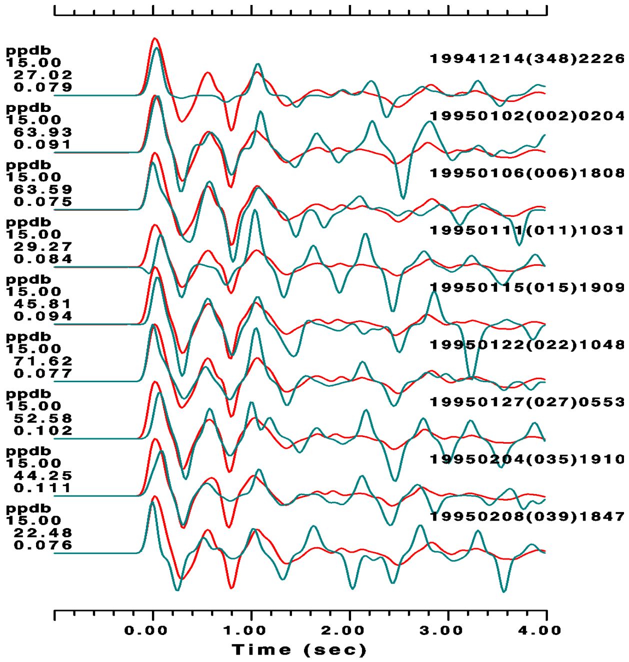

Fig. 4a. *ppdb* waveform fit from linearized inversion. Blue traces are observed receiver functions (from time-domain deconvolution), red traces are calculated from the inverted model in Fig. 4b.

Fig. 4a. Ajuste das FR calculadas (em vermelho) e observadas (em azul) para a estação ppdb com o modelo da Fig. 4b.

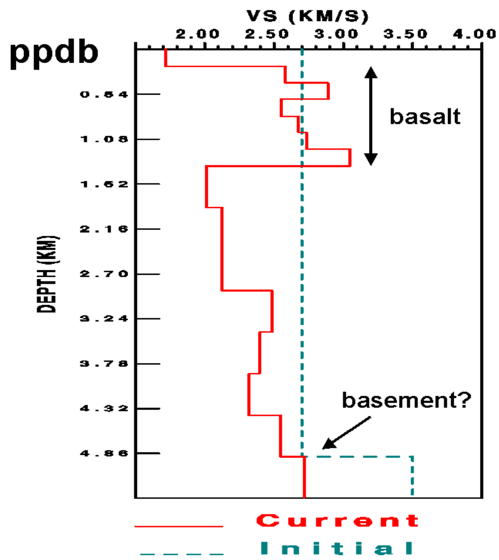

Fig. 4b. *ppdb* inverted model. Blue dashed line is initial S-wave velocity model; red line is inverted model. Basalt thickness is 1.2 km. Basement depth is not well defined in this inversion run.

Fig. 4b. Modelo para o perfil de velocidade S sob ppdb. Linha tracejada azul é o modelo inicial; linha vermelha o invertido. A espessura do basalto é de 1.2 km, mas o embasamento não está bem definido.

Fig. 4 shows the results for station *ppdb*. The basement depth is not well defined in this run, but the total basalt thickness is clearly seen as a 1.2 km layer, very consistent with the expected values from Fig. 2. The transition from high basalt velocity to low sedimentary velocity is seen in the RFs as a clear trough about 0.3 s after the first peak (Fig. 4a). Note that a thin low-velocity layer (Bauru Group) appeared in the inverted model (Fig. 4b). The effect of this thin superficial layer may be seen in some RFs as a small inflection in the first peak (at ~0.1s, Fig. 4a) which was modelled as a broader pulse.

The inversion results for station *trib* are shown in Figs. 5a,b. Note that the first peak in the RFs of Fig. 5a are shorter (compared with those of *ppdb*) which did not require a low-velocity surface layer in the inverted model. This is consistent with the fact that station *trib* sits directly on a basalt outcrop. The basalt thickness is mainly defined by the negative peak (trough) just less than 0.2s after the first arrival (Fig. 5a). The modeled basalt thickness (Fig. 5b) of about 0.5 km is consistent with the expected value form the regional contours (Fig. 2).

The total thickness of the basin beneath *trib* was modeled as about 3.8 km, consistent with the contour map (Fig. 1) which indicates a basement depth near 4 km.

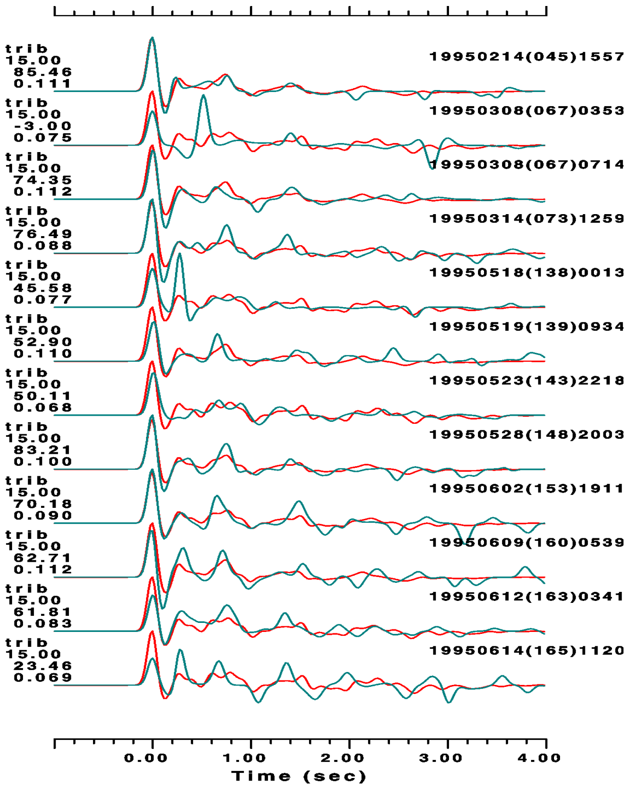

Fig. 5a . *trib* waveform fit from linearized inversion. Blue traces are observed receiver functions (from time-domain deconvolution), red traces are calculated with inverted model in Fig. 5b.

Fig. 5a. Ajuste das FR calculadas (em vermelho) e observadas (em azul) para a estação trib com o modelo da Fig. 5b

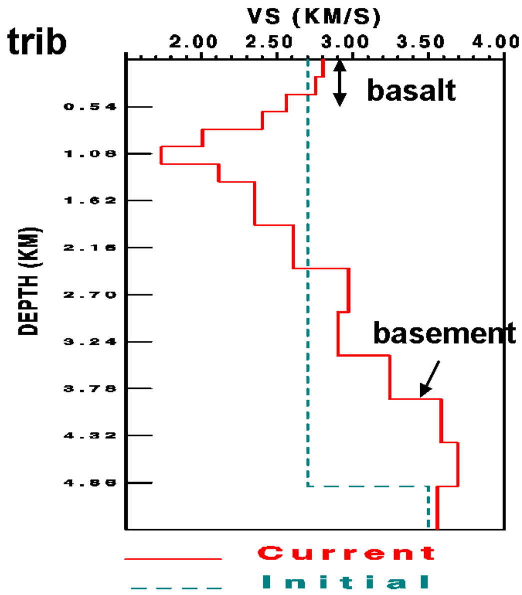

Fig. 5b. *trib* inversion. Blue dashed line is initial S-wave velocity model; red line is final inverted model. Basalt thickness is 0.5 km. Basement depth well defined at 3.8 km.

Fig. 5b. Modelo para o perfil de velocidade S sob trib. Linha tracejada azul é o modelo inicial; linha vermelha o invertido. A espessura do basalto é ~0.5km e a profundidade do embasamento está bem definida em 3.8km.

Conclusions

High-frequency receiver functions are a promising tool to investigate deep sedimentary basins in Brazil, specially because of the nearby deep earthquakes of the Andean subduction zone. Despite non-uniqueness in the inversion of receiver functions (Ammon et al., 1990), these preliminary inversion tests for stations *ppdb* and *trib* show excellent agreement with the expected main features of the Paraná basin beneath the stations.

Acknowledgments

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