Sedimentary Thickness in the Paraná Basin using High-Frequency Receiver Function: Estimated Depth of a Buried Graben in the MS/GO border.

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Abstract (Font: Arial Bold, 9)

Receiver Functions (RF) in the frequency range 0.1 to 1 Hz have been extensively used to estimate crustal thicknesses. Here we show that high frequency RF (1 to 5 Hz) can be used to determine the thickness of sedimentary basins. However, the non-uniqueness of the RF inversion requires other information to be added in the inversion scheme. For example, different velocity profiles of the shallow (<100m) layers have a large effect in the inversion results for the deeper layers. We used a shallow seismic refraction survey to constrain the seismic velocities in the first 30m. Surface-wave group-velocity dispersion was used to constrain the average crustal S-wave velocity. Long-period RF was jointly inverted with high-frequency RF to estimate both the deep crustal and the sedimentary structure. Station CDSB is located in the northern part of the Paraná Basin, in the middle of a low-gravity anomaly, which has been attributed to a buried graben. Our inversion of the RFs suggests the graben could be about 7-8 km deep, consistent with gravity modeling, but has a thick basalt flood layer, perhaps related to the graben evolution.

Introduction

Teleseismic receiver functions have become a routine method to study deep crustal and upper mantle structure. It consists in deconvolving the vertical component from the radial component in teleseismic records, usually low-pass filtered at about 1Hz, to remove near source effects and isolate the response of the structure beneath the station in terms of all the P to S conversions in the major crustal discontinuities (e.g. Ammon et al., 1990; Wilson and Aster, 2003). It has been extensively used to map crustal thicknesses and the major discontinuities in the upper mantle transition zone.

Here we use receiver functions with frequencies up to about 5 Hz to investigate structural features of the Paraná sedimentary basin. High frequency receiver functions had been used successfully by An & Assumpção (2004) to estimate thicknesses of the basalt layer and basement depth beneath some stations in São Paulo state.

In the northern part of the intracratonic Paraná basin, two NS trending negative Bouguer anomalies (about 30 and 15 mGal), near the Mato Grosso/Goiás state border (Fig. 1), have been interpreted as evidence of a graben system buried beneath Paleozoic sediments (Vidotti et al.,1998). These possible grabens may indicate extensional processes related to the origin of the Paraná basin.

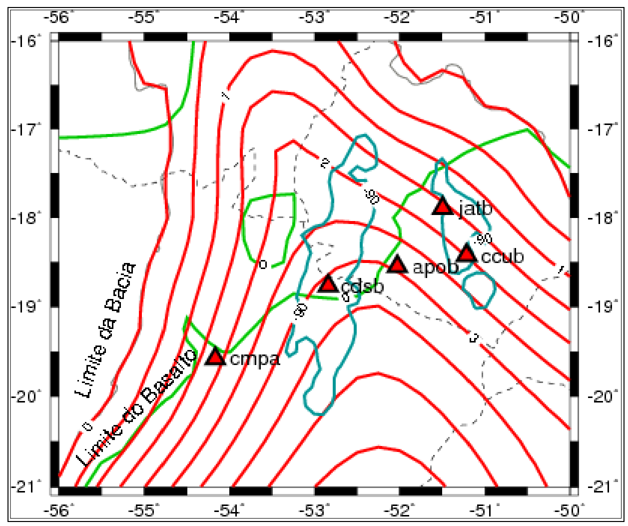

Fig.1 *– Northern part of the Paraná basin with estimated basement depths (red lines). The blue contours indicate the two negative Bouguer anomalies which may indicate buried grabens. Red triangles denote seismic stations. Green lines indicate limits of the Serra Geral basalt outcrop.*

Receiver Functions

It has been shown by Langston (1979) and Ammon et al.(1990) that the deconvolution of the vertical from the radial component removes the source and instrument effects and isolates the effects of the structure beneath the station. The trace corresponding to this deconvolved signal (called Receiver Function) contains all the P-to-S conversions and reverberations from interfaces beneath the station arriving as an S-wave at the receiver. Fig. 2 illustrates the main signals from a single discontinuity.

We take advantage of the nearby Andean teleseisms, with epicentral distance in the range 15^o to 25^o, deeper than about 100km, and magnitudes higher than 4.7 mb, which contain the necessary high-frequency energy. The larger depths are necessary to avoid attenuation of the high frequencies in the asthenosphere beneath the source.

We used the time-domain deconvolution of Ligorría and Ammon (1999) with a low-pass Gaussian filter at about 5 Hz (Gaussian width parameter = 10). For each event, receiver functions were calculated for time windows varying from 10 to 20 s, and the best resulting window was selected.

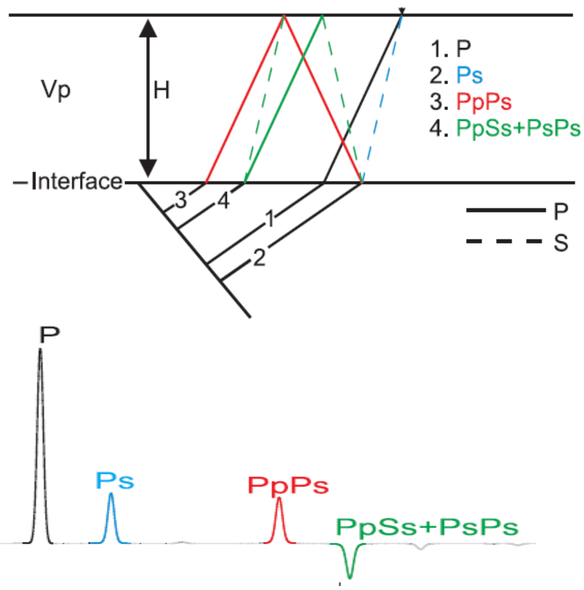

***Fig. 2. Top**) P-to-S conversions from a single interface. **Bottom**) receiver function with the direct P phase, the Ps conversion and the multiple reflections.*

Effect of shallow layers in the inversion

It is known that inversion of RF to estimate the velocity profile is a non-unique problem (e.g., Ammon et al., 1990) because any peak in the RF trace can be interpreted as a direct Ps conversion from a certain interface or as a multiple reflection (such as PpPs in Fig.2) from a shallow interface. For this reason joint inversion of RF with other kinds of data are necessary to restrain the range of possible solutions, such as MT sounding (Zevallos et al., 2009). Joint inversion of RF with surface-wave dispersion (Julià et al., 2000; Julià et al., 2008) is a powerful tool to reduce non-uniquenesses.

For the inversion of the RFs of CDSB station we used the regional group-velocities of Rayleigh and Love waves as determined by the surface-wave tomography of Feng et al. (2004, 2007). However, the regional surface-wave dispersion covers the period range 10 to 60 s which helps control the average crustal velocities from roughly 10 to 60 km, and cannot help reduce ambiguities in the shallow sedimentary layers.

As an example of the effect of the shallow layers in the inversion, Fig. 3 shows the RFs calculated with two different models. The first peak in the RF is slightly displaced from 0 time which is due to the soil layer, such as a 25 m thick soil with Vs=300 m/s overlying a soft sediment layer. The second large peak observed at 0.9s is most probably due to the sediment/basement interface (bottom of the sedimentary basin). However, it could also be modeled by a multiply reflected conversion at a depth of about 100m (boundary between soft and hard sediments)

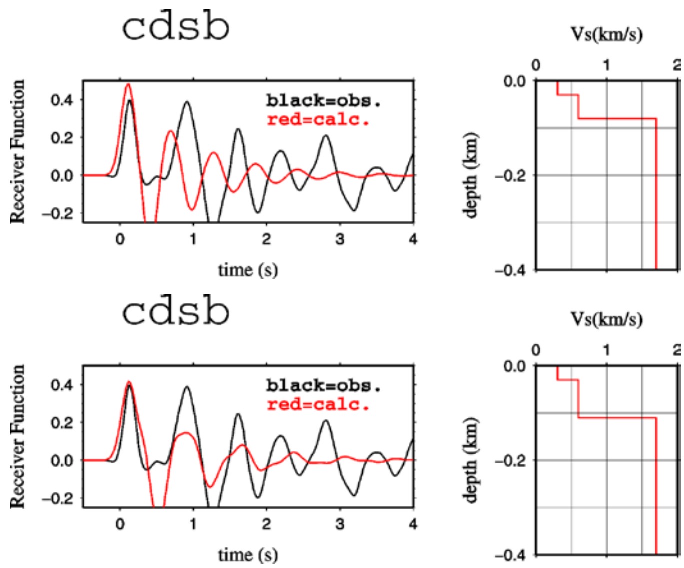

***Fig. 3**. Effect of shallow soil structure on the RF. Black trace is the observed RF (Gauss filter =10), red trace is calculated with the model on the right.*

These ambiguities in the RF interpretation can only be eliminated with additional information on the shallow structure. For this reason, a shallow seismic refraction line was shot at the station site to constrain the first layers of the model near the surface. Fig. 4 shows the P-wave tomography inversion obtained with the WET method – wavepath eikonal traveltime (Schuster & Quintus-Bosz, 1993)

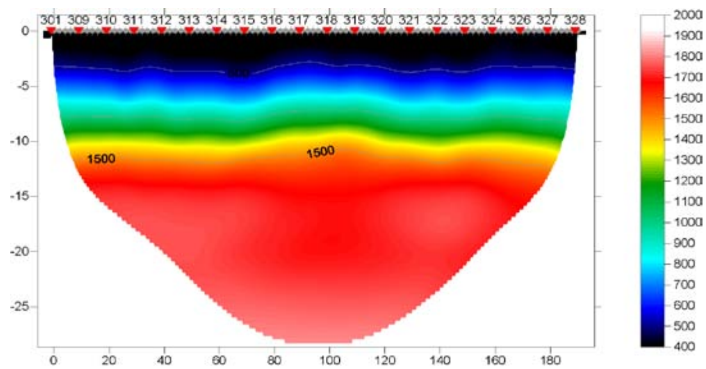

Fig. 4. P-wave tomography from a 200m long seismic refraction line with shots every 10m. Depth in meters, colors are Vp (m/s).

Results

In the final inversion of the high-frequency RF to obtain the sedimentary structure beneath station CDSB we also used two low-frequency RFs (to help constrain deeper interfaces such as the Moho) and Rayleigh-wave group velocities (to constrain the average crustal Vs) as shown in Fig. 5. The joint inversion is a linearized iterative process which needs a starting model (blue line in Fig.6). In the inversion, the shallow layers were forced to remain close to the structure obtained with the shallow P-wave tomography (Fig. 4) where a Vp/Vs = 2 was used.

Fig. 6 shows the resulting model. The peak in the HF RF at 0.9s (Fig. 5) is the Ps conversion from the sediment/ basement interface which can be seen at about 4 km (Fig. 6, top) where Vs changes from 3.0 to 3.5 km/s.

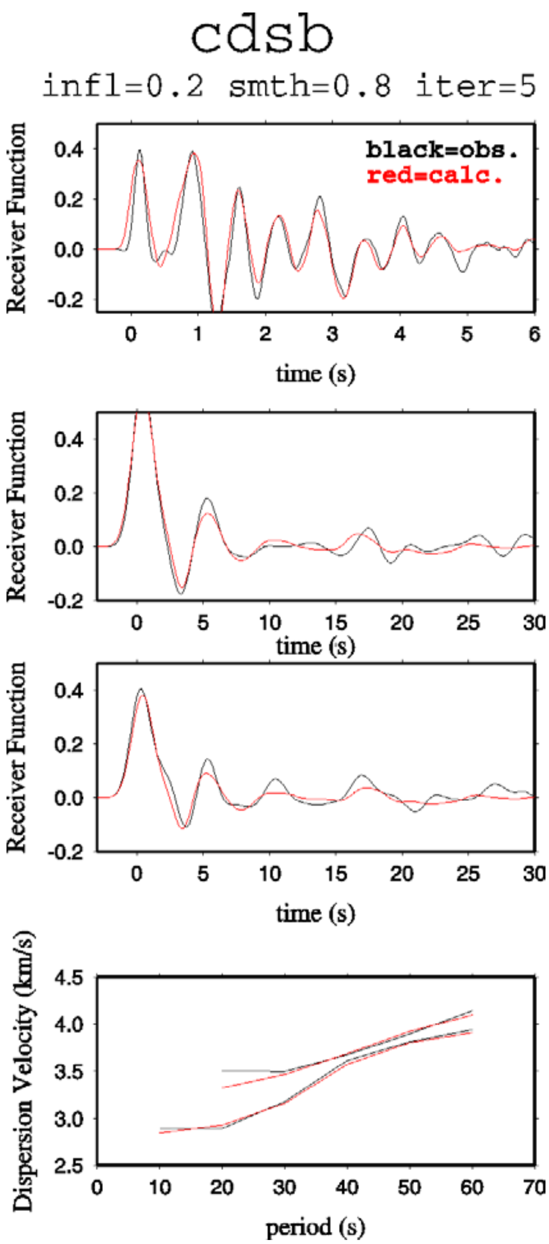

***Fig. 5**. Observed (black lines) and calculated (red) RFs and group-velocities. Top diagram is the high-frequency RF (Gauss=10 ; the two middle diagrams show the low-freq. RFs (Gauss=1); bottom plot shows the Love and Rayleigh group velocities.*

The low-frequency RFs show the Moho Ps conversion at 5s and the first multiple at about 17s. These phases were used to estimate the average crustal Vp/Vs ratio as 1.80 which was used in the inversion for all layers below the soil and soft sediments. The Moho depth can be seen at about 42 km depth (Fig. 6, bottom). Different starting models have little effect on the final inverted model.

A high-velocity layer can be seen between 4 and 5.5 km depth. Two interpretations are possible:

a) The graben beneath CDSB is 4.0 km deep, and the low-velocity channel is an upper crustal anomaly,

b) The depth of the graben is actually at around 7-8 km, and the high-velocity layer between 4.0 and 5.5 km, is a thick diabase sill, or a flood basalt layer.

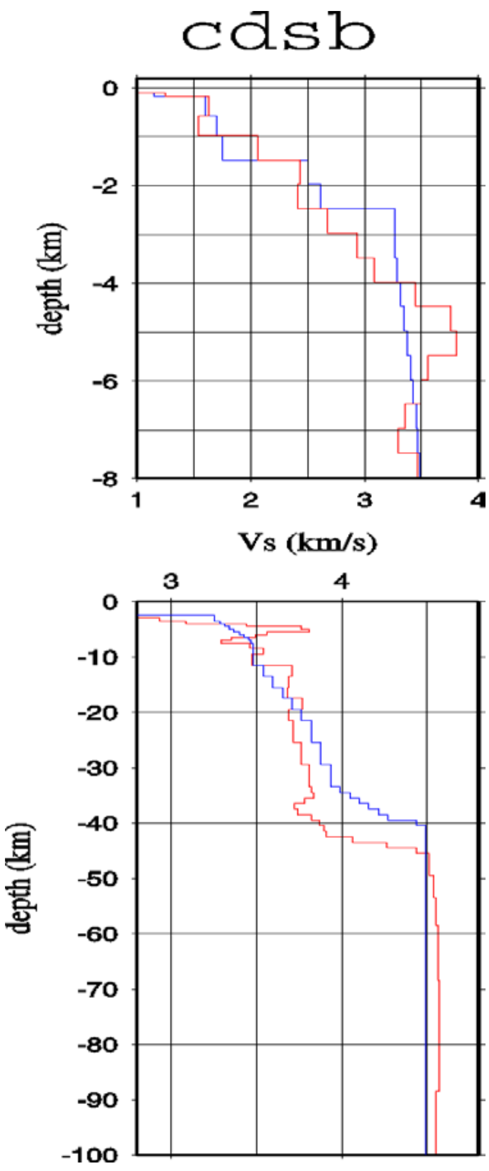

***Fig. 6**. Inverted model. Blue and red profiles denote the initial and final model.*

Conclusions

High-frequency RFs can provide valuable information on the structure of sedimentary basins. However, the non-uniqueness of the RF inversions requires other complementary geophysical information to constrain the possible solutions. Shallow seismics can provide important constraints on the RF inversion by fixing the soil/soft-sediment structure which affects the resulting structure of the deeper layers.

S-wave velocities of igneous/metamorphic rocks typical of the upper crustal basement are usually around 3.4 to 3.6 km/s. The S-wave profile beneath station CDSB (Fig. 6, top) shows a high-velocity layer (4.0 to 5.5 km deep) overlying a low-velocity zone (5.5 to ~7km deep). Two interpretations can be proposed:

a) the basement depth is at 4.0 km, and the low-velocity channel indicate some anomalous rocks in the upper crustal basement, or

b) the graben is actually 7-8 km deep, and the high-velocity layer is an intra-sediment feature. In this case the high S-wave velocity would probably indicate a volcanic layer. This could be a very thick sill, or perhaps a flood basalt layer resulting from extensional processes which originated the graben.

Vidotti et al. estimated the bottom of this graben to be at about 8 km depth, by modeling the gravity anomalies in the northern part of the Paraná basin, which favors the second interpretation.

Acknowledgment

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