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The structure of the Amazonian craton: Available geophysical evidence

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ABSTRACT

The Amazonian craton, which covers a large area of South America, and is thought to have been stable since the end of the Mesoproterozoic, has recently benefited from a series of regional geophysical surveys. The Amazonian craton comprises the northern Guyana shield and the southern Central Brazil shield. It has become the main subject of seismological studies aiming to determine crustal thickness. Moho thickness maps that cover a large part of the South American continent summarize these studies. Receiver function studies, aided by surface wave dispersion tomography, were also useful tools applied in the region over the past decade. These have been improved by the addition of temporary and permanent regional seismological arrays and stations. An interesting NNW-SSE Moho depth anomaly, pointing to crustal thickening of up to 60 km in the central Guyana shield and a 50 km thick anomaly of the southern Central Brazil shield were recently identified. Areas with crustal thickening correspond to Paleoproterozoic magmatic arcs. The upper mantle seismic anisotropy in part of the region has been determined from SKS splitting studies. The currently available seismic anisotropy information shows that the orientation of the determined anisotropic axis is related to the frozen in anisotropy hypothesis for the Amazonian craton. The orientation of the anisotropic axis shows no relation to the current South American plate motion in the Amazonian craton. Most recently, detailed information for the two shields has benefited from a series of high-resolution, regional aerogeophysical surveys, made available by CPRM, the Brazilian Geological Survey. In addition to the mentioned contribution from seismology for imaging deeper crustal structures, regional gravity surveys have been expanded, adding to previous Bouguer anomaly maps, and deep drilling information from early exploration efforts have been compiled for the Amazon basin, which covers the Amazonian craton separating the Guyana and Central Brazil shields.

1. Introduction

The geologic setting and corresponding deep structure of the Amazonian craton, composed of the northern Guyana, and the southern Central Brazil shields, have historically been less investigated than other neighboring Precambrian areas of South America. This is mainly because this area was populated later than the eastern and western portions of South America, where old existing settlements along either the Atlantic or Pacific margins enabled the establishment of the first universities and research institutes in the continent, mostly during the last century. Most of the area contained within the Amazonian craton is still very remote and covered with thick soil and dense tropical forest, limiting access to its bedrock compared with other areas. Despite the existing logistical difficulties, the Amazonian craton has been the subject of several regional investigations over the past few decades, aiming to secure definite information about its shallow bedrock structure and to determine its deep geologic structure. In this work, a summary is presented of the results of some of the important surveys conducted in the Brazilian sector of the area, which used various modern geophysical methods and furnished the first insights into the deep geologic structure of the craton. Some of the results already gathered under the mentioned surveys indicate that applied geophysical methods are able to fulfill at least part of the persisting curiosity shared by the pioneers who first studied the geology of this region.

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2. Deep structure of the Amazonian craton from seismological studies

2.1. S-wave receiver function analysis

Vinnik (1977) introduced a new version of the crust receiver function analysis method of Langston (1977, 1979), where the Z, N, and E records are rotated into the L, Q, and T ray coordinate system, allowing a better separation of the P-to-SV conversions from the P-wave train. This is a modified version of the receiver function technique improved by Kind and Vinnik (1988) and Yuan et al. (1997), which has been extensively used for investigating crustal thickness using teleseismic data. Zhu and Kanamori (2000) later proposed a migration scheme to estimate crustal thickness, which is commonly applied with the original receiver function analysis. The main contribution of Vinnik (1977) was the introduction of a distance-move out correction to the original method of Langston (1977, 1979). This modified version of the original receiver function method, which is now a standard tool to investigate the crustal and mantle structure (Owens et al., 1987; Ammon et al., 1990), was used in the Amazonian craton by Krüger et al. (2002), and by Rosa et al. (2012).

The most frequently applied version of the receiver function method uses the converted shear waves derived from teleseismic P waves incident from underneath each station. The converted waves, after crossing discontinuities, such as the Moho, have their dominant amplitude recorded by each instrument, primarily their corresponding radial component. Following Krüger et al. (2002), if one assumes that the vertical component of the record represents the source time function, the radial component of the seismograms can be equalized with respect to the source time function. This can be achieved by deconvolving the vertical from the radial component of each seismogram. The resulting deconvolved trace is called a receiver function, and it theoretically represents the transfer characteristics for shear waves underneath each station (Krüger et al., 2002).

Application of the method to the recorded data of a given station usually requires several years of operation of a fixed, or temporary, seismograph in the field, and data processing requires a careful, visually controlled, data selection over many seismograms, which involves experienced data analysts for trustworthy results.

Although very useful for the investigation of the structure and thickness of the crust and lithosphere, usage of the S-wave receiver function method in South America (specially in Amazonian craton areas) has been limited, mainly due to the very small number of stations and events located at proper epicentral teleseismic distances for the analysis. This is in contrast to a good number of studies conducted in other areas of Brazil (*e.g.*, An and Assumpção, 2006; Assumpção et al., 2002), from which important results on crustal and upper mantle structure from seismological data gathered from denser seismological networks have been made available in the most recent two decades.

The S-wave receiver function method was used by Heit et al. (2007) to investigate the thickness of the South American lithospheric plate along a roughly E-W profile across the continent, which cuts through the southern portion of the Amazonian craton, *i.e.*, the Central Brazil shield and its eastern limits. Interesting aspects of their results are the estimates of Moho depth and lithosphere-asthenosphere boundary depth variations underneath the Central Brazil shield. The determined Moho depth values underneath the BDFB (Brasília) GTSN station, and the SAML (Samuel) GSN station, are respectively 43 and 40 km (Fig. 1), while the lithosphere-asthenosphere measured boundary depth is, respectively, 160 and 130 km, for BDFB and SAML. It is worth mentioning that Heit et al. (2007) estimate that the procedure they applied to convert the resulting time values from the lithosphere-asthenosphere measurements can introduce an error of approximately 10–15 km into the measured lithosphere thickness. Although the work of Heit et al. (2007) includes only two results along a wide E-W extent of the Central Brazil shield, these results could be viewed as corresponding to a possible crustal and lithospheric thinning towards the western border of the Central Brazil shield. These results are within the expected possible error bounds of the method employed in this determination, so that a definite conclusion on this may still be premature. The resulting Moho depth of 43 km obtained by Heit et al. (2007) for the BDFB Brasília station is the largest result they obtained while processing data gathered from the Brazilian stations. The results match those obtained by Assumpção et al. (2004) using P-wave receiver functions at the same site.

A noteworthy contribution to the understanding of the lateral variations found in the deep structure of eastern South America, including the Amazonian craton, is that of Lloyd et al. (2010). They combined a set of newly determined Moho depth values from the receiver function analysis of seismic stations deployed in eastern Brazil to the Moho depth values obtained by previous receiver function determinations in South America. The combined set of Moho depth values (totaling 225 determinations across the continent, including the dataset of França and Assumpção (2004), from receiver function analysis were added to a large set of Rayleigh wave group velocity determinations and Rayleigh wave waveform analysis of paths crossing the South American plate. The consolidated Rayleigh wave group velocity and waveform data included those from previous work by the same research group on the same parameters (Feng et al., 2004, 2007; Van der Lee et al., 2001). The Moho depth values from receiver function analysis served as point constrains for an inversion scheme applied to the entire dataset. The results of the inversion process of Lloyd et al. (2010) produced a map of the Moho depth in South America and indicated that the Moho depth is largest for areas with crustal ages ranging from 2.0 to 3.0 Ga. Moreover, Lloyd et al. (2010) found that the mapped Moho depth values decrease toward younger crust areas of the Tassinari and Macambira (1999) provinces (Fig. 1). In the particular case of the Amazonian craton, they did not see much difference in the Moho depth between the Proterozoic and Archean crustal areas. On the other hand, Lloyd et al. (2010) detected a crustal thickening zone, roughly oriented NNW-SSE, corresponding to the central portion of the Guyana shield and continuing underneath the Amazon basin into the eastern portion of the Central Brazil shield. The crustal variations observed by Lloyd et al. (2010) match those discussed by Rosa et al. (2014) at the western border of the Guyana shield, in the Pitinga region located about 300 km north of Manaus, where there appears to be a crustal thickening north of Pitinga (PTGA, IRIS-GSN station) and crustal thinning towards the Amazon basin near Manaus (Krüger et al., 2002). Although the determined map of Moho depth of South America by Lloyd et al. (2010) was obtained using an inversion process of the Rayleigh wave group velocity, which usually includes larger errors than phase velocity measurements, and despite the long path samples used in the process, the results seem to be consistent with the main geologic regional features known of the Guyana and Central Brazil shields of the Amazonian craton. Moreover, their results also show continuing features underneath the Phanerozoic Amazon basin, which separates the two shields. Therefore, the Moho depth model proposed by Lloyd et al. (2010) could be assumed as the first approximations of the Moho depth variations to date on the Amazonian craton. A more recent contribution, which includes an updated crustal thickness map of South America (Chulick et al., 2013) confirms the finds of Lloyd et al. (2010).

An innovative, more detailed view of the Moho depth of the