Tectonophysics 583 (2013) 1–15

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Shear-wave velocity structure of Antarctica from Rayleigh-wave analysis

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ARTICLE INFO

Article history:
Received 21 May 2012
Received in revised form 1 October 2012
Accepted 4 October 2012
Available online 12 October 2012

Keywords:
Rayleigh wave
Shear wave
Crust
Upper mantle
Antarctica

ABSTRACT

The elastic structure beneath Antarctica is shown by means of S-velocity maps for depths ranging from zero to 400 km, determined by the regionalization and inversion of Rayleigh-wave dispersion. The traces of 93 earthquakes, occurring from 1990 to 2011, have been used to obtain Rayleigh-wave dispersion data. These earthquakes were registered by 30 seismic stations located in Antarctica. The dispersion curves were obtained for periods between 5 and 250 s, by digital filtering with a combination of MFT and TVF filtering techniques. Later, all seismic events (and some stations) were grouped to obtain a dispersion curve for each source-station path. These dispersion curves were regionalized and inverted according to the generalized inversion theory, to obtain shear-wave velocity models for a rectangular grid of 20×20 points. The shear-velocity structure obtained through this procedure is shown in the S-velocity maps plotted for several depths. These results agree well with the geology and other geophysical results previously obtained. The obtained S-velocity models suggest the existence of lateral and vertical heterogeneities. The zones with consolidated and old structures present greater S-velocity values than the other zones, although this difference can be very little or negligible in some case. Nevertheless, in the depth range of 10 to 45 km, the different Moho depths present in the study area generate the principal variation of S-velocity. A similar behaviour is found for the depth range from 80 to 230 km, in which the lithosphere–asthenosphere boundary generates the principal variations of S-velocity. Finally, a new and interesting feature obtained in this study should be highlighted: the definition of the LAB and the base of the asthenosphere (for the whole study area), for depths ranging from 80 to 230 km and from 180 to 280 km, respectively.

1. Introduction

The great ability of the Rayleigh-wave dispersion analysis to delineate the Earth's deep structure is well known (Corchete, 2012, in press, submitted for publication). This methodology allows the features of the Earth's structure to be determined, because it is well known that the surface-wave dispersion (Rayleigh-wave dispersion) is related to the Earth's structure crossed by the waves (represented by the S-velocity structure). Thus, the features of the elastic structure for any region of the Earth can be studied through the analysis of Rayleigh-wave dispersion. In this paper, the features of the elastic structure beneath Antarctica (and its surrounding area) will be revealed through this analysis. Antarctica is one of the regions for which there are relatively few seismic studies, due to the particular conditions of this continent (it is covered by large and thick ice sheets), which have made difficult the development and maintenance of high-quality seismic networks. Nevertheless, since the crust and upper mantle of this area are among the most poorly studied, knowledge of detailed seismic structure of this area would be of great importance. Fortunately, in the last years, some international agencies such as GSN (Global Seismographic Network), IRIS (Incorporated Research Institutions for Seismology), GEOFON (GEOFON Global Seismic Network) and GEOSCOPE (GEOSCOPE Observatory) jointing to local agencies (as TransAntarctic Mountains Seismic Experiment) have been able to develop and support new and permanent broad-band digital seismic stations. As a result of this, in the last twenty years high-quality seismic records have been made available from seismographic databases for Antarctica.

In a pioneer study, Roult et al. (1994) investigated the crust and upper mantle structures using surface waves. They used periods of the fundamental modes of Rayleigh-wave phase-velocity ranging from 60 to 300 s, performing maps of regionalized phase velocity for some selected periods (from 76 to 166 s), but no seismic velocity structure was obtained with depth. Later, Roult and Rouland (1994), also in a pioneer study, perform a review of these results and other previous results obtained for the Antarctic area, showing and discussing a few P- and S-wave velocity distributions with depth (from 0 to 100 km of depth). Finally, Ritzwoller et al. (2001) performed the first surface-wave tomography for Antarctica and the surrounding area. In this study, they obtained shear velocity maps from top of the upper mantle to 250 km of depth (although the resolution decreases drastically with depth from 150 km), using periods of fundamental modes ranging from 18 to 175 s for Rayleigh waves and from 20 to 150 s for Love waves.

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0040-1951/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2012.10.013

It should be noted that no 3D S-velocity structure has been obtained for Antarctica and its surrounding area, from surface-wave tomography, for depths ranging from 0 to 45 km and from 250 to 400 km. Furthermore, the S-velocity structure, obtained in the above-mentioned previous study, shows a poor resolution for the depth range from 150 to 250 km. For it, the goal of the present study is the determination of the elastic structure (S-velocity structure) beneath Antarctica and the surrounding area, from Rayleigh-wave analysis, for the whole depth range from 0 to 400 km, because no 3D S-velocity structure has been obtained, until now, for this study area in this complete depth range. This Rayleigh-wave analysis will consist of filtering of Rayleigh waves, to obtain dispersion curves from 5 to 250 s. This dispersion analysis will be performed in several steps. First, all seismic events will be grouped in source zones to get an average dispersion curve for each source-station path. Then, the dispersion curves will be obtained by digital filtering with a combination of the Multiple Filter Technique (Dziewonski et al., 1969) and Time Variable Filtering (Cara, 1973). Thus, a set of source-station averaged dispersion curves will be calculated. This set of dispersion curves will be regionalized and then inverted according to the generalized inversion theory, to get S-wave velocity models for a rectangular grid defined in the study area. Finally, these models will be plotted to obtain a 2D mapping of the 3D S-wave velocity structure, for the study area. The period range to be obtained in the present study, by digital filtering, will be wider than the period range measured in the above-mentioned previous studies. Thus, the determination of the 3D S-velocity structure, in the whole depth range from 0 to 400 km, will be more accurate in the present study than the other above-mentioned previous study, in which no surface-wave dispersion was measured in the period ranges from 5 to 18 s and from 175 to 250 s. This lack of information in the above-mentioned previous study caused the lack of a 3D S-velocity structure, for the depth range from 0 to 45 km, and the bad resolution of the 3D S-velocity structure for the depth range from 150 to 250 km.

2. Data set

In this study, a list of 93 earthquakes occurring from 1990 to 2011 in the neighbouring of Antarctica has been considered (Supplement 1). These earthquakes have been registered by 30 seismic stations located at this continent (Supplement 2). From these stations digital data are available, recorded with a different instrument for each available channel (Supplement 6). From all these channels, only the records for the channels (vertical components): BHZ, LHZ, BLZ, and LLZ; and for the channels (horizontal components): BH1, LH1, BH2, and LH2; have been considered as the most suitable data for this study, because the period interval of best registration for these channels is between 1 or 5 and 200 or 250 s (period interval in which the frequency response is almost flat). This period interval (from 1 to 250 s) is more suitable for exploring the elastic structure of the Earth, for a depth range of 0 to 400 km of depth. For this reason, the above mentioned channels have selected from the all available channels.

Also, to ensure the reliability of the results, only the earthquake traces in which a well-developed Rayleigh wave train is present, with a very clear dispersion, have been considered. Thus, many records have been discarded.

Logically, the instrumental response must be taken into account to avoid the time lag introduced by the seismograph system (and all distortions produced by the instrument). This correction recovers the true amplitude and phase of the ground motion, allowing the analysis of the true dispersion of Rayleigh waves. For this reason, all the traces considered in this study were corrected for instrument response.

3. Pre-processing and filtering

For the pre-processing and calculation of dispersion curves, the computation method detailed by Corchete et al. (2007) was followed. In this paper, only a brief review of the principal concepts of this methodology will be presented.

3.1. Grouping of stations and seismic events

It is well known that the Rayleigh waves propagated along very near epicentre-station paths show similar dispersion curves, because they cross the same earth structure and sample the same elastic properties of the medium. As a consequence of this, it is possible to group all seismic events listed in Supplement 1 in source zones, as listed in Supplement 3, to get source-station paths from epicentre-station paths. These source zones are defined as a location at which seismic events with similar epicentre coordinates have occurred. The coordinate differences for a group of events must be less than or equal to 1° in latitude and longitude, to be able to group them in the same source zone. Then, an average dispersion curve for each source-station path can be obtained, when the dispersion curves calculated for the traces of the events of this source zone (recorded at the same station) are averaged. In this way, any small deviations obtained are considered errors, which can be described by the standard deviation. It should be noted that some stations considered in this study also show very similar coordinates. Thus, they have been also grouped using the same criteria described above for the events, defining new station codes to denote these average stations. These new stations are listed in Supplement 4. Fig. 1 shows the path coverage obtained for the study area (given by the source-station paths).

3.2. Dispersion analysis

The Rayleigh-wave group velocity for the trace of each event registered has been measured by means of the combination of digital filtering techniques: Multiple Filter Technique (MFT) and Time Variable Filtering (TVF), as shown in the flow chart displayed in Fig. 2. As an example of this filtering process, the application of this combination of filtering techniques to the trace of the event 81 (recorded at DRV station) will be detailed. The MFT has been applied firstly to this trace as it is shown in Fig. 3. This trace and the dispersion curve obtained are used to compute the digital filtered signal by using the TVF. Fig. 4 shows the time-variable filtered signal resulting from the TVF. Finally, Fig. 5 shows the final dispersion curve obtained after application of the MFT to the filtered signal. A comparison between Figs. 3 and 5 shows the benefits of the proposed filtering process. It should be noted that a combination of MFT and TVF works better

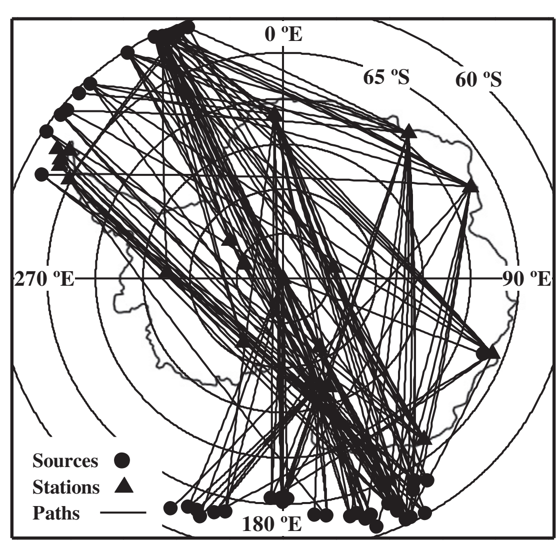

Fig. 1. Path coverage of the Rayleigh waves (149 paths).