Tectonophysics 730 (2018) 81–99

Contents lists available at ScienceDirect

Tectonophysics

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

Thermal structure of the Panama Basin by analysis of seismic attenuation

Carlos A. Vargas[a,*], José E. Pulido[a], Richard W. Hobbs[b]

[a] Universidad Nacional de Colombia, Department of Geosciences, Bogotá, Colombia
[b] Durham University, Durham, United Kingdom

ARTICLE INFO

Keywords:
Thermal structure
Panama Basin
Seismic attenuation
Curie point depth
Heat flow

ABSTRACT

Using recordings of earthquakes on Oceanic Bottom Seismographs and onshore stations on the coastal margins of Colombia, Panama, and Ecuador, we estimate attenuation parameters in the upper lithosphere of the Panama Basin. The tomographic images of the derived coda-Q values are correlated with estimates of Curie Point Depth and measured and theoretical heat flow. Our study reveals three tectonic domains where magmatic/hydrothermal activity or lateral variations of the lithologic composition in the upper lithosphere can account for the modeled thermal structure and the anelasticity. We find that the Costa Rica Ridge and the Panama Fracture Zone are significant tectonic features probably related to thermal anomalies detected in the study area. We interpret a large and deep intrinsic attenuation anomaly as related to the heat source at the Costa Rica Ridge and show how interactions with regional fault systems cause contrasting attenuation anomalies.

1. Introduction

Seismic attenuation is a measure of the energy dissipation of seismic waves as they spread inside the Earth. Observational and experimental data suggest that this phenomenon is controlled by the temperature, the mineral composition, and the presence of melts, fluids, volatiles, and cracks (Sato et al., 1989; Karato, 1993; Fehler and Sato, 2003; Artemieva et al., 2004). The attenuation parameter derived from the coda of S-waves, or the inverse of the seismic quality factor (Q^{-1}), depends on the frequency and the travel time, and consequently on the travel-path from the hypocenter of the earthquake to the seismic station (Singh and Herrmann, 1983; Jin and Aki, 1988), which makes it a suitable tool for investigating the sub-seismic structure lithosphere.

Attenuation is generated by two phenomena: (1) scattering (Q_{sc}^{-1}), which is a diffusion process of seismic energy due to interaction of the waves with heterogeneities in the lithosphere; and (2) intrinsic absorption (Q_{in}^{-1}), that represents the conversion of elastic energy into other forms of energy (e.g. heat or piezoelectricity). The combination of these parameters is responsible for the total observed attenuation. Hence, quantifying the contribution of Q_{sc}^{-1} and Q_{in}^{-1} has been a subject of considerable interest because offers information about internal structure and processes in the Earth interior (Vargas et al., 2004; Del Pezzo, 2008; Sato et al., 2012; Prudencio et al., 2013; Del Pezzo et al., 2016). Discrimination these two parameters can be estimated through multiple scattering models (Zeng, 1991; Hoshiba, 1991) or by using a hybrid approach, e.g. using the simple backscattering hypothesis and a multiple scattering model (Wennerberg, 1993).

A simple method for estimating the coda waves' attenuation under the simple backscattering hypothesis was proposed by Aki and Chouet (1975), who suggested that the parameter coda-Q (Q_c) is: (1) independent of recording site and event location; (2) independent of earthquake magnitude for events with M < 6; and (3) it has a close relationship with the local geology of the recording site. This method has been used widely to interpret the heterogeneity of the Earth (Fehler and Sato, 2003). However, there is not consensus regarding the meaning of Q_c^{-1} and its relationship with Q_{sc}^{-1} and Q_{in}^{-1} (Sato and Fehler, 2009). Notwithstanding, mapping these parameters offer valuable information about the lateral heterogeneities caused by tectonic domains and magmatic processes, as well as the thermal structure (Vargas and Mann, 2013; Prudencio et al., 2013; Del Pezzo et al., 2016).

Knowledge of the thermal structure of a region contributes to understanding its tectonic and magmatic behavior, as well as allowing inferences about its evolution and composition. The main approach for estimating the thermal structure is by using direct information from heat-flow measurements. However, these measurements are mainly limited to conductive heat-flow in sediments which can be perturbed by local fluid-flow. Fortunately, recent improvements in the estimation of the Curie Point Depth (CPD) based on analysis of magnetic anomaly datasets provides an alternative method for inferring the thermal structure of broad areas (Spector and Grant, 1970; Ravat, 2004; Ross et al., 2004; Vargas et al., 2015; Salazar et al., 2017). This regional approach allows the estimation of the depth at which magnetic minerals transit from ferromagnetic to paramagnetic states due to the effect of rising temperature. Many of these studies contrast heat-flow

* Corresponding author.
E-mail address: cavargasj@unal.edu.co (C.A. Vargas).

https://doi.org/10.1016/j.tecto.2018.02.017
Received 9 June 2017; Received in revised form 21 February 2018; Accepted 25 February 2018

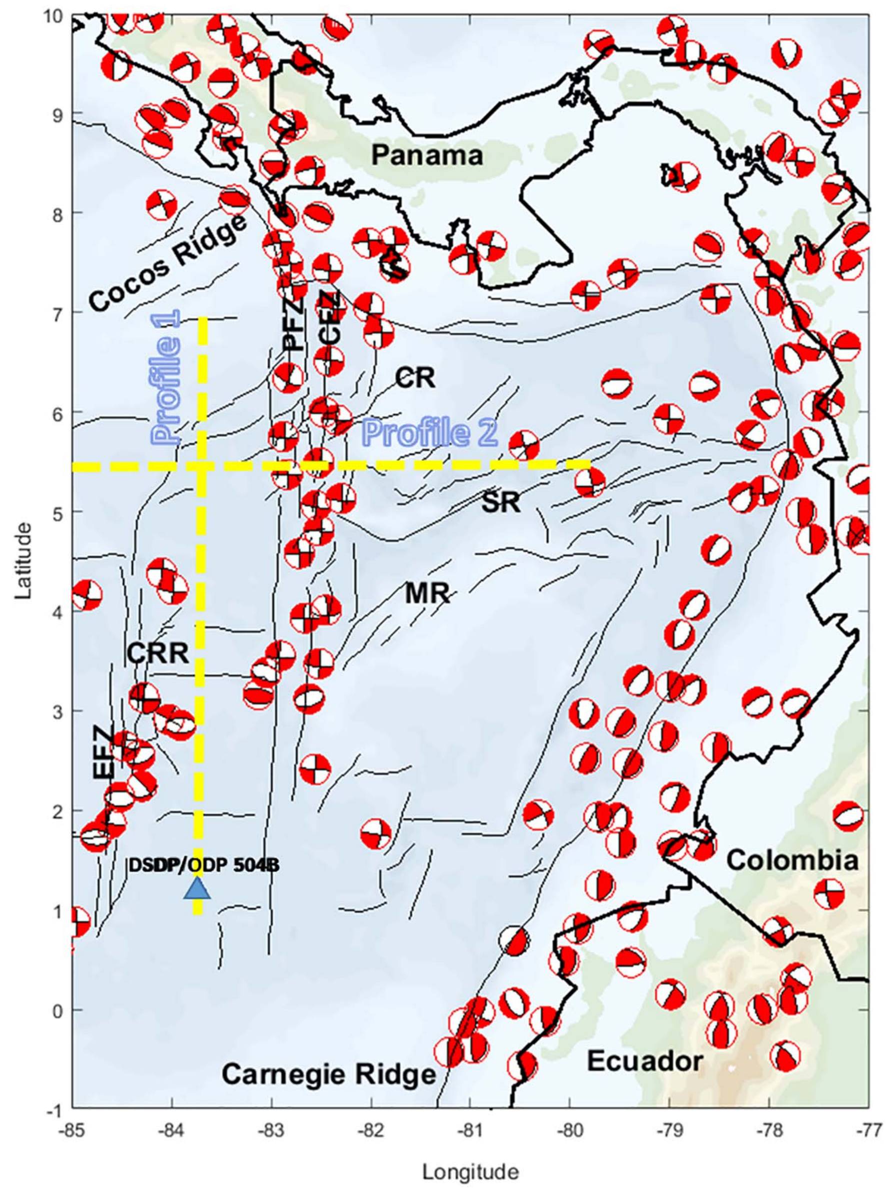

Fig. 1. Main tectonic features of the Panama Basin (thin-black lines). Shorelines are presented in bold-black lines. SR: Sandra Rift; MR: Malpelo Ridge; PFZ: Panama Fracture Zone; EFZ: Ecuador Fracture Zone; ER: Ecuador Ridge; CFZ: Coiba Fracture Zone; CR: Coiba Ridge; CRR: Costa Rica Ridge. Focal Mechanisms are extracted from the Global CMT Catalogue (Ekström et al., 2012). Blue triangle shows the location of the well DSDP/ODP 504B. Two dashed-yellow lines correspond to tomographic profiles discussed later. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

observations and CPD estimations (Tanaka et al., 1999; Ruiz and Introcaso, 2004; Yang et al., 2017) for investigating the distortion of the thermal structure in the lithosphere.

In this study, we analyze the attenuation properties of the Panama Basin by discriminating $Q_{sc}{}^{-1}$ and $Q_{\text{in}}{}^{-1}$ based on $Q_c{}^{-1}$ and $Q_S{}^{-1}$ observations. This region offers an important opportunity to correlate the spatial distributions of these attenuation parameters with its thermal structure, which is associated to the formation and interaction of young lithospheric plates. The resulting attenuation structure is compared with Curie Point Depth (CPD) calculations using magnetic anomalies reported by Maus et al. (2007) and Dyment et al. (2015), and from direct observations of heat flow in the basin (Davis et al., 2004; Hasterok et al., 2011; Kolandaivelu et al., 2017).

2. Geotectonic setting

The Panama Basin is an area enclosed by the continental margins of Ecuador, Colombia and Panama to the East and North, and the Carnegie and Cocos ridges to the south and northwest (Fig. 1). It sits within the Galapagos gore, a region of oceanic crust formed at the Cocos-Nazca spreading center, east of the East Pacific Rise (Hardy, 1991). Our study focuses on the eastern part of the basin whose prominent features include the Panama Fracture Zone (PFZ), the Costa Rica Ridge (CRR), the Ecuador Fracture Zone (EFZ), and the Malpelo (MR), Coiba (CR) and Sandra ridges (SR). The formation of the basin was caused by the split of the oceanic Farallon plate into Cocos and Nazca plates at the beginning of the Miocene (Lonsdale, 2005) and interaction with the Galapagos hot-spot. Currently, the basin is moving eastward relative to South America with seismic activity primarily along the continental margins where focal mechanisms suggest extensional processes in proximal areas to the trench and compressional processes associated to the subduction of the Nazca Plate. The N-S orientated PFZ, EFZ and CFZ show focal mechanisms related to right-lateral movement, and the CRR and other ridges show a diversity of focal mechanisms. There is also seismic activity along other east-west structures related to the SR but this is less well constrained compared to that of the continental margins