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The inner inner core of the Earth: Texturing of iron crystals from three-dimensional seismic anisotropy

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Abstract

We present a three-dimensional model of the seismic anisotropy and texturing of iron crystals in the inner core. The form of the anisotropy changes suddenly at slightly less than half of the inner core radius. The outer part is composed of iron crystals of a single phase with different degrees of preferred alignment along the spin axis of the Earth. The inner part may be composed of a different phase of crystalline iron or have a different pattern of alignment.

Keywords: inner inner core; inner core anisotropy; seismic waves; iron alignment

1. Introduction

The Earth's solid inner core was formed from the solidification of a molten iron alloy in the liquid outer core (Jacobs, 1953) over much of the Earth's history. The inner core has been found to possess strong anisotropy for seismic waves (Morelli et al., 1986; Woodhouse et al., 1986; Creager, 1992; Tromp, 1993; Song and Helmberger, 1993), due to the preferred orientation of the iron crystals composing the inner core (Brown and Mcqueen, 1986). Recent studies have generally suggested a very complex structure for the inner core. The anisotropy changes significantly with depth (Shearer, 1994; Song and Helmberger, 1995) and the amplitude change can be sharp at shallow depth at certain localities (Song and Helmberger, 1998). The inner core exhibits hemispherical variations in anisotropy (Tanaka and Hamaguchi, 1997; Creager, 1999; Garcia and Souriau, 2000), isotropic velocity (Niu and Wen, 2001), and attenuation(Yu and Wen, 2006). Lateral variation is also present at scales of hundreds of km (Creager, 1997; Song, 2000) to a km (Cormier et al., 1998; Vidale and Earle, 2000). The inner core boundary (ICB) may also be bumpy (Krasnoshchekov et al., 2005; Wen, 2006; Cao et al., 2007). The aspherical structure has provided important markers for observations of the inner core rotation (Song and Richards, 1996; Creager, 1997; Vidale et al., 2000; Laske and Masters, 2003; Zhang et al., 2005). Recently, an innermost inner core (IMIC) with a radius of about 300 km was proposed by Ishii and Dziewonski (Ishii and Dziewonski, 2002) to have a distinct form of anisotropy from that of the overlying inner core. Evidence for a possible anisotropy change was subsequently reported (Beghein and Trampert, 2003; Sun and Song, 2004; Cormier and Stroujkova, 2005; Cao and Romanowicz, 2007) at perhaps a larger radius of 400–500 km. Here we present a model of 3D anisotropy and texturing of iron crystals in the inner core. We show a drastic change of the form of the inner core anisotropy at a radius of about 590 km from 3D non-linear inversion and direct modeling of the travel times of core-traversing waves (PKP). The change appears to be sharp, occurring over a depth range of less than 150 km. The radius of the inner sphere is almost half the radius of the inner core, thus we refer to it as the "inner inner core" (IIC) (Anderson, 2002), rather than the IMIC (Ishii and Dziewonski, 2002), and the outer part as the outer inner core (OIC).

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2. Three-dimensional anisotropy

We performed non-linear iterative inversions of a large set of high quality PKP differential travel times that have been acquired over the years. Below we give a brief outline of the inversion. Details are presented in a separate paper (Sun and Song, 2008). Differential travel times are formed between PKP (DF) branch (traversing the inner core) and PKP(BC) (turning at the bottom of the outer core) or PKP(AB) (turning at mid-outer core) branch (see Supplementary materials, Fig. S1). A small set of PKP CD-DF differential times from Niu and Wen (2001) is also used to help constrain the topmost inner core. Differential time residuals are then derived by subtracting predictions for the AK135 model (Kennett et al., 1995), and, furthermore, by

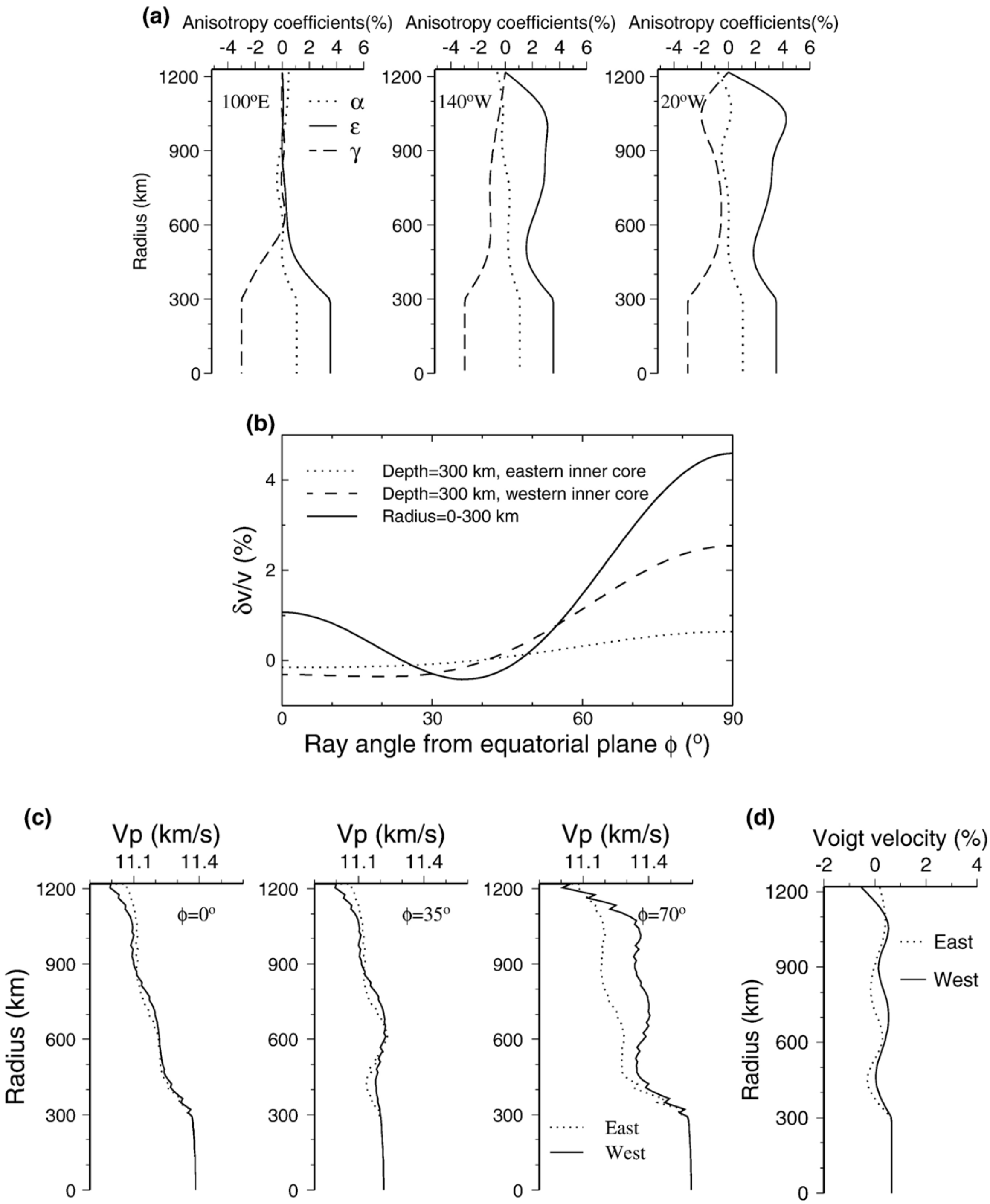

Fig. 1. Displays of inner core anisotropy from our non-linear inversion. (a) Anisotropy coefficients as a function of radius at three control longitudes. The values for other longitudes are represented by linear interpolation of these values. (b) Comparison of the *P*-velocity perturbations at different depths of the inner core as a function of ray direction. (c) Averaged velocity profiles for eastern and western hemispheres of the inner core at different directions. (d) Voigt averages for the eastern and western hemispheres.