[S6-P01] Proper Methodology to Compare Seismological and Mineral Physics Constrains of the Earth's Inner Core

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Abstract

Determination of inner-core composition is a multi-disciplinary endeavor, i.e., all currently available inner-core compositions are based upon matching seismological observations with mineral physics constraints. However, because the inner core is surrounded by the liquid outer core, P and SV waves in the inner core can be observed, but not SH waves. This introduces bias in seismological modeling for the average seismic wave speed, i.e., the shear wave speed in models such as PREM is not the true isotropic speed, but an SV speed. On the other hand, mineral physics studies use elements of the elasticity tensor to calculate an average (e.g., Voight and Reuss averages) to obtain isotropic properties of anisotropic material to compare against seismological values. The observational bias due to the liquid outer core does not exist in such calculations, and this poses inconsistency in comparing mineral physics constraints to seismological inner-core properties. This study overcomes this observational bias by establishing the proper framework in which to compare the seismic observations with mineral physics constraints. A simple mapping between the elements of the elasticity tensor and the seismologically-obtained "isotropic" moduli is derived using a first order perturbation approach. We show that this observational bias leads to a significant complication when the shear-wave speed provided in PREM is used to constrain inner core composition, and has implications for determining the presence of partial melt within the inner core.

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[S6-P02] Grain boundary sliding in high temperature deformation of directionally solidified hcp Zn alloys, and implications for the deformation mechanism of Earth's inner core

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Abstract

Earth's inner core exhibits elastic anisotropy, but the cause of the texturing is uncertain: solidification, deformation, or some combination. In experiments presented here we deformed in torsion directionally solidified Zn - 3 wt pct Sn alloys at .97 the melting temperature of pure Zn. We used a Zn-rich alloy because Zn is hexagonal close-packed at atmospheric pressure, as is likely Fe under inner core conditions. The directionally solidified alloys have the textured, columnar dendritic microstructure that has been proposed for the inner core. As a control we deformed in torsion the same alloy at the same temperature, but with a starting microstructure that is comparatively fine-grained, equiaxed, and untextured. We find evidence that the directionally solidified alloys deform by means of grain boundary sliding, presumably accompanied by diffusion near the ends of the columnar crystals in order to preserve macroscopic shape. We also find that the directionally solidified alloys require approximately three times the torque to deform to the same strain than do the untextured alloys. Grain boundary sliding and greater hardness are due to insufficient slip systems to accommodate the strain, as a result of the texturing. This is supported by microcracking in the deformed directionally solidified alloys. Although the inner core is unlikely to exhibit semi-brittle deformation, the experiments suggest that a directionally solidified inner core could have a higher viscosity than one with a finer-grained, untextured microstructure, and that grain boundary sliding may be a dominant deformation mechanism, in spite of the large grain size.

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[S6-P03] hcp-Fe alloy as the candidate of the Earth's inner core

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Abstract

Increasing evidence from experimental and theoretical studies suggests the inner core could be *hcp*-Fe alloyed with light elements (Li. *et al.*, 2001; Lin*et al.*, 2003, Vočadlo *et al.*, 2009;Kuwayama *et al.*, 2009, Antonangeli, *et al.*, 2010; Kamada *et al.*, 2012, Hirose, *et al.*, 2013;Litasov *et al.*, 2016;Mori *et al.*, 2017). Locating the candidate compositions that can simultaneously match the geophysical and cosmochemical constraints is not an easy task, which requires extensive searching over the compositional space. Using *ab initio*molecular dynamics calculations, we have studied the compositional, structural, and elastic properties of *hcp*-Fe alloys at 360 GPa up to the melting temperature (Li. *et al.*, 20017a; Li. *et al.*, 20017b; Li. *et al.*, 20018). We successfully established a mixing model for the elastic properties of *hcp*-Fe alloys based on the properties of binaries, and the accuracy and applicability of this model were confirmed by ternary calculations. This allows us to do an instantaneous search within the whole compositional and elastic property spaces. Compositions were found to match both the inner-core density and sound velocities.

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[S6-P04] The Paleomagnetic Reversal Record and Variations of Inner Core Anisotropy

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Abstract

Inside the rapidly convecting outer core (OC) lies the solid inner core (IC), steadily growing from solidifying OC-iron as the Earth slowly cools down. Seismic evidence suggest that the IC is not a homogeneous sphere, but is composed of several distinct layers, such as an isotropic upper layer (UIC) (Waszek & Deuss 2011), and an innermost inner core (IMIC) (Isshi & Dziewonski 2002; Begein & Trampert 2003; Nui & Chen 2008). Quasi-hemispherical variations between an Eastern and Western hemisphere have also been widely reported (Tanaka & Hamaguchi 1997; Deuss et al. 2010; Irving & Deuss 2011). This study investigates the possible connection of the origin of this seismic structure to the paleomagnetic field.
First, we make a model dividing the IC into layers of distinct anisotropy using a dataset of 6961 traces, including data from Irving & Deuss (2011), Waszek & Deuss (2011), and Lythgoe et al. (2013), as well as newly picked PKP-data, and found radial boundaries at depths of approximately 30km, 60km, 125km (UIC), 275km, and 745km (IMIC). The varying anisotropy of these layers likely relates to a different crystal structure and/or preferred lattice orientations. The origin of this variation is unknown, but several explanations exist that can be divided into two classes. (i) The crystals are frozen at solidification on the inner core boundary (ICB). Due to varying conditions of OC-flow at the ICB (Bergman 1997) or the magnetic field (Karato 1993), the crystals align differently and as such record conditions of the OC flow. (ii) The structure is deformed after solidification, either to balance differential growth rate at the equator and the poles (Yoshida et al. 1996; Deguen et al. 2011) or by the magnetic field (Buffett & Wenk 2001). If this deformation only extends into the upper layer, the IC might record the OC flow conditions. In both cases, the observed IC structure depends on the large scale flow of the OC.

To estimate possible ages of the layers, creating, as it were an 'IC stratigraphy', we applied the IC growth model of Buffet et al. (1996). Using various feasible values of CMB heat flux and thus age (Olsen 2016), we composed possible IC growth histories, and converted depth to stratification age. These ages are compared to distinct regimes of the paleomagnetic reversal record, namely superchrons, which are periods lasting millions of years with a stable magnetic field, and periods of hyperactivity, where the magnetic field switched fast and often, as these likely relate to stable and volatile convection in the OC respectively (Biggin et al. 2012).

In two cases, the proposed ages of the IC layers overlap nicely with the paleomagnetic

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regimes: (i) models with an IC nucleation (ICN) somewhere between 1.3 – 1.1 Ga. This corresponds to the reported ICN of Biggin et al. (2015) based on a controversial interpretation of the paleomagnetic intensity. (ii) An ICN of 0.60 – 0.56 Ga, which is more in line with most of the recent estimations of ICN based on CMB heat flux of 1.0 – 0.5 Ga (Olsen 2016). These results are not definitive in any measure, but they are suggestive of a possible relation between paleomagnetic regimes and IC seismic structure. The next step is to establish the exact nature of this proposed connection in order to discriminate accurately between the two previously mentioned possibilities. As such, additional constraints might be provided on the age the IC as well as the origin of the varying anisotropy of the IC.

[S6-P05] Axially dependent Inner Core anisotropy from low order inner core convection

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Abstract

Inner core anisotropy was proposed thirty years ago to explain differences in travel times of the inner core phase (PKIKP) on polar and equatorial paths (Morelli et al., 1986). Over time, models of inner core anisotropy have become very complex, with evidence for depth dependence, hemispherical variations, and other localised features. Some models propose a constant strength of anisotropy in excess of 4% in the western hemisphere of the inner core, sharply contrasting with eastern hemisphere with anisotropy of _~1%. The strength of anisotropy and sharpness of the hemispherical contrast of existing models are difficult to reconcile with predictions from mineral physics and dynamical models of inner core growth. We examine the trends of PKIKP travel times on newly acquired polar paths from recent deployments of broadband arrays in Alaska and Antarctica. We observe large travel time anomalies in Alaska associated with the Alaskan subduction zone, indicating upper mantle contamination of these paths. Meanwhile, other polar paths suggest that the inner core velocity structure depends not on radius but on the distance from the rotation axis. The strength of the anisotropy linearly increases from 0% at the top of the eastern hemisphere and 2.0% at the top of the western hemisphere to a maximum of 3.5% at 400 km away from the rotation axis in the western hemisphere. We propose a model of mode 1 convection in the inner core parallel to the rotation axis that results in alignment of iron crystals, but with the centre, and thus strongest anisotropy, offset into the western hemisphere.

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[S6-P06] Probabilistic estimation of splitting coefficients and their uncertainties, for the core sensitive modes, using matrix autoregression

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Abstract

Splitting coefficients are useful observations to infer velocity, density and attenuation structure of the deep earth interior (and particularly their relative behavior) but, as usually posed, the measurement of these parameters from the Earth's normal mode spectra is a highly non-linear inverse problem. Additionally, complete source information is needed but is typically unknown for very large earthquakes and a trade-off exists between earthquake source mechanism and attenuation. Here, we combine matrix autoregression and a fully non-linear probabilistic sampling to quantify the splitting coefficients and their uncertainties. This method enables us to eliminate the source information from the problem. We first validate the feasibility of this joint technique through several synthetic experiments and apply it to the data for 19 core-sensitive spheroidal (S) modes measured for earthquakes from 1994 to 2016. We also implement a model selection criterion that balances the trade-off between the measure of fit and complexity. The selection criterion indicates that the anelastic splitting coefficients are not required for most of the core-sensitive modes except for those with strong shear-wave energy in the inner core. The estimated anelastic splitting amplitudes are low except for a few modes, e.g. 11S1 and 3S2. For these modes, the anelastic splitting amplitude is more than half of the elastic part but with strong positive frequencies near the poles. This indicates that the shear waves travel faster and strongly attenuate along polar paths such that the m=0 singlet remains poorly observed for these modes. The observations also support the inference that the inner core has a small Q-value for shear waves and may be a reason that the observation of inner core shear waves (PKJKP) is difficult. The elastic splitting coefficients are similar to those recently published in that the zonal coefficients are dominant for all the core-sensitive modes, but our values are different for most of the modes. Additionally, our uncertainties are higher for most of the splitting coefficients and can be even larger when we consider errors due to unknown model parameterization in the inversion.

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