The Paleomagnetic Reversal Record and Variations of Inner Core Anisotropy

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Introduction

The age of the inner core (IC), as well as the origin of its anisotropy variation with depth, figure 1, have long been a mystery. By comparing the radial variation in anisotropy to the paleomagnetic reversal record, using realistic IC growth models, we investigate the possibility of a relation between the flow pattern of outer core (OC) convection, which is recorded by paleomagnetic data, and the seismic anisotropy of the IC.

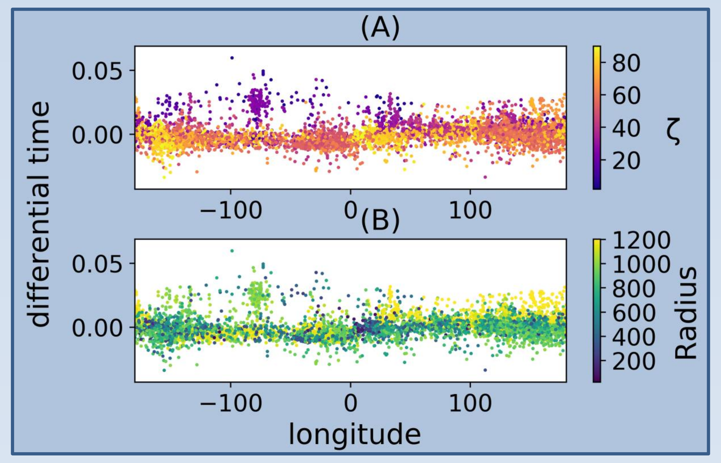

Figure 1: Differential time vs. longitude of all data. (A) ζ-variation shows strong polar anisotropy in the west. (B) dt dependence on depth, especially clear in the east.

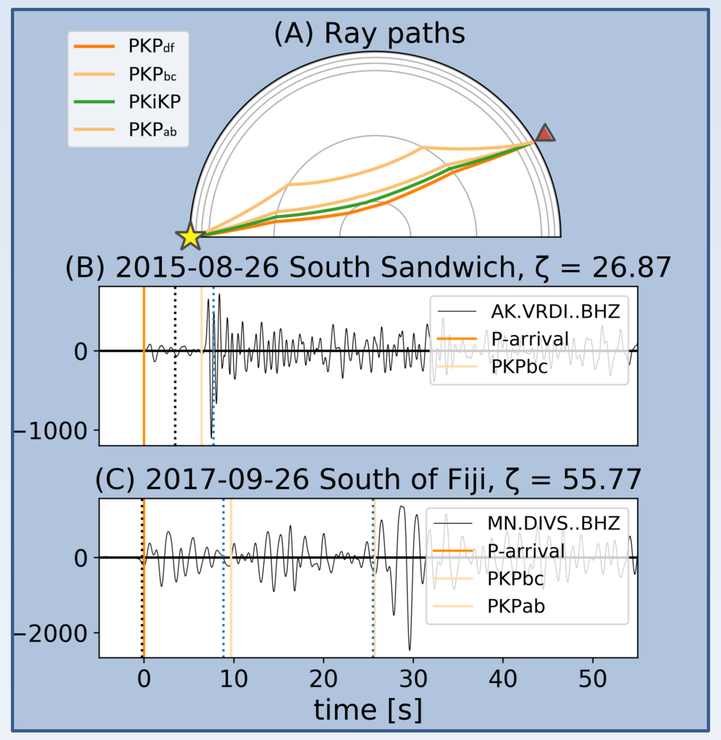

Figure 2: (A) Rays of the used phases. (B) Polar waveform with picks. (C) Equatorial waveform with picks.

Seismological IC-Model

We constructed an anisotropy model of the IC with a dataset of 6961 seismic waves, using PKPab, PKPbc, and PKiKP as reference phase to PKPdf rays (figure 2), by fitting the data to the anisotropy equation[1]:

$$\frac{\delta t}{T} = a + b\cos^2\zeta + c\cos^4\zeta \qquad (1)$$

δt denotes the difference in offset of the PKPdf-arrival and the reference phase between the model (AK135) and the data, T is the predicted IC travel time, and ζ represents the angle of the ray in the IC with the rotation axis. The resulting anisotropy model consisted of a 6 layered IC, with boundaries at depths of approximately 30km, 60km, 125km, 275km, and 745km, figure 3(G). As it is well established that the eastern 'hemisphere' differs from the west[2], we allowed for hemispherical variation within the layers. Our model is shown in figure 3.

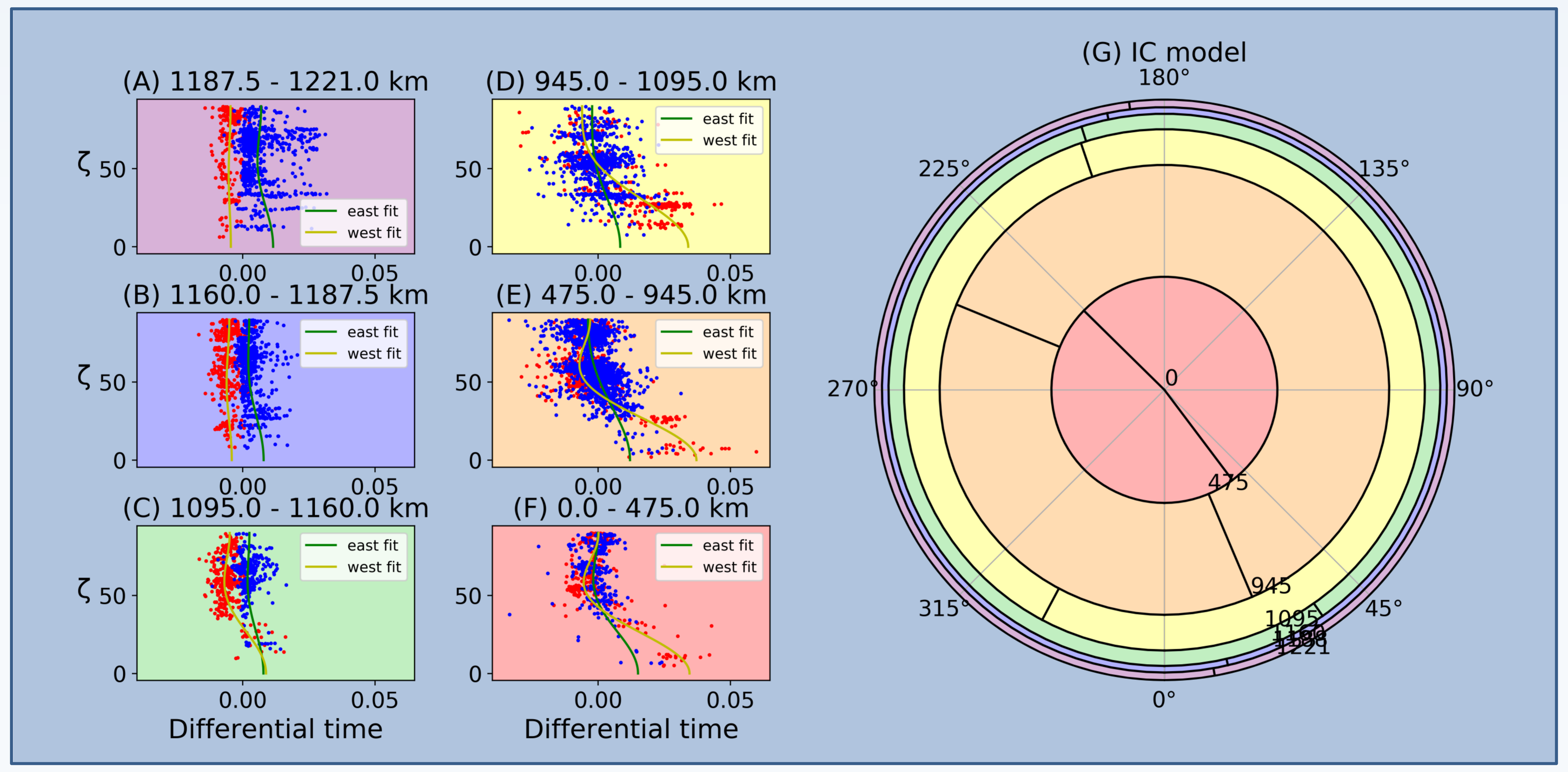

Figure 3: (A) – (F) The fit of our anisotropy model to the seismic data, using eq. 1. (A) & (B) show the upper layers that are isotropic in both hemispheres. In the lower layers (C)-(F) anisotropy appears strongly in the west and to a lesser extend in the east. (G) The resulting IC-model, including hemispherical variation, which can clearly be seen in the seismic data. The hemispherical boundaries that optimized the fit are shown.

IC Growth and Stratigraphy

The varying anisotropy is likely caused by differences in crystal structure. During IC growth the crystals either 'freeze' at solidification at the inner core boundary (ICB) or the crystal structure deforms plastically after solidification. If this deformation only extends to a thin upper layer, the crystal alignment can in both cases depend on the OC-flow pattern[3,4] or variations in the magnetic field[5,6] and it can 'record' variations of OC-flow. Under the assumption of relatively shallow freeze-in of IC crystals, we convert IC depth to solidification age, using a growth model of the IC[7], and create an IC stratigraphy. Since the age of the IC is not yet determined, we considered a range of likely ages (1.5 – 0.5 Ga). Two stratigraphy models, corresponding to the end members of this range are shown in figure 4.

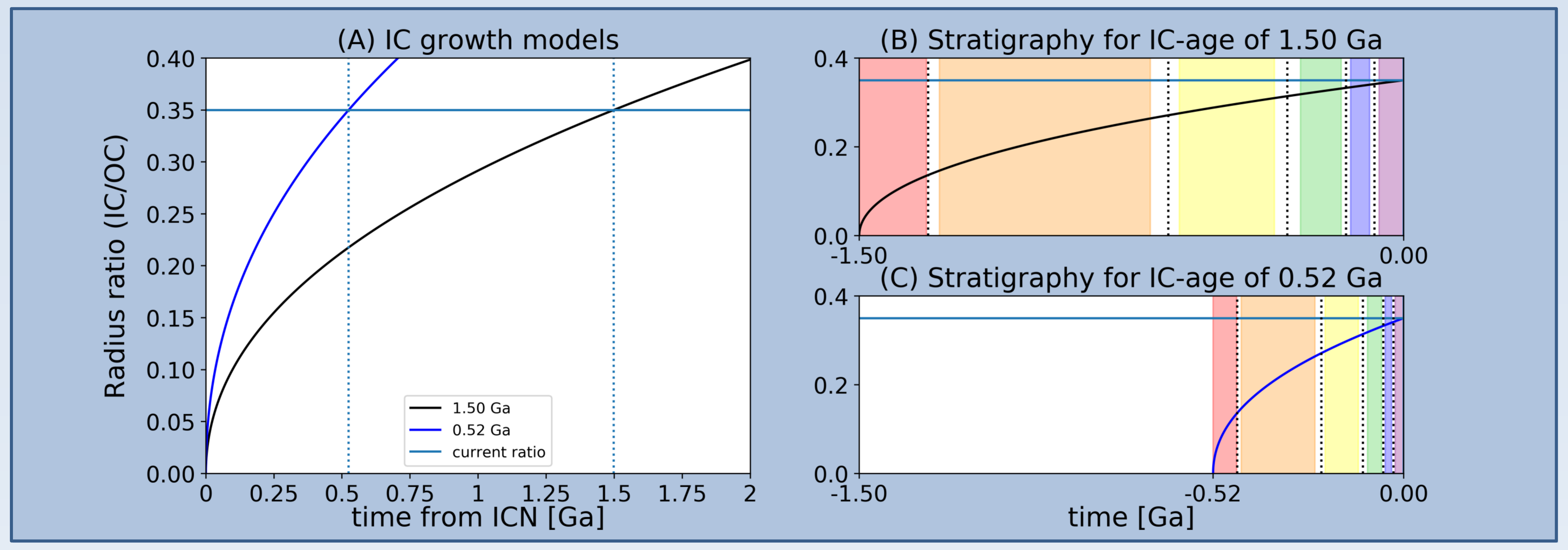

Figure 4: (A) Two IC growth model[7] corresponding to the current IC-age estimated, reaching the current IC/OC-ratio 1.5 and 0.5 Ga after IC-nucleation. (B) and (C) show the depth – age conversion (stratigraphy) for these ages respectively.

Paleomagnetic Reversal Record

OC-flow regimes are identified by analysing the paleomagnetic reversal record. Figure 5 shows the paleomagnetic reversal frequency data from the past 1 Ga, as well as an interpretive model[8]. The highlighted areas correspond to periods of distinct paleomagnetic behaviour, and thus OC-flow. The lighter areas depict periods of hyperactivity, where the field reverses often. It is associated with a high and laterally varying heat flux across the core mantle boundary (CMB) and a weak dipole moment[9]. The darker areas correspond to superchrons, where the field is strong and stable, and the CMB heat flux relatively low[9]. The striped regions (age > 320 Ma) are still under discussion, and generally the older the period, the less certain its actual existence. Especially the superchron of 1 Ga is highly questionable, but shown here for inclusivity.

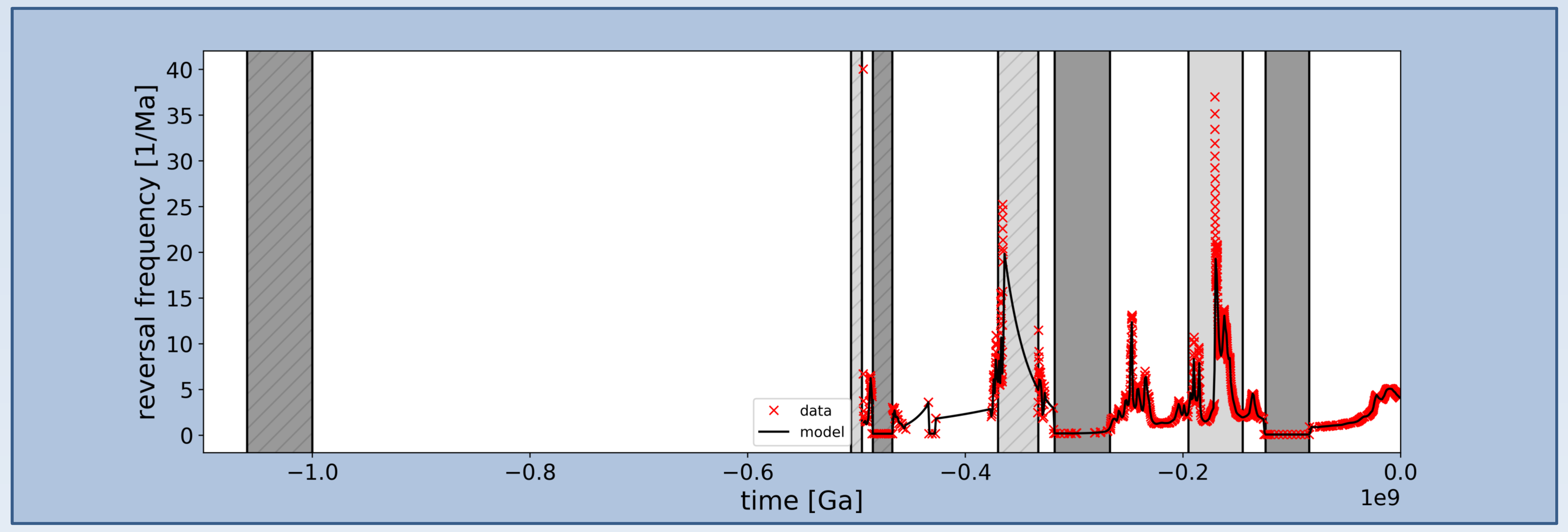

Figure 5: Paleomagnetic reversal record. Red crosses correspond to measured data[8], while the black line depicts an interpretive model of that data[8]. The highlighted areas indicate identifiable outer core regimes, the lighter depict hyperactive periods, the darker areas correspond to superchrons[9].

Interpretation

By comparing the paleomagnetic reversal record with models of IC stratigraphy, two IC growth models show a correlation between variations in anisotropy and geomagnetic regimes: IC Nucleation (INC) at 1.3 – 1.1 Ga, figure 6 (A) – (C), or an ICN at 0.64 – 0.53 Ga, figure 6 (D) – (E). With an ICN within either one of these ranges, a change of anisotropy in the IC coincides with the on- or offset of a paleomagnetic period, and thus with a change in OC-flow behavior. These results are not definitive at all, but they are suggestive of a possible relation between the paleomagnetic reversal frequency and variations in inner core anisotropy, which could explain the origin of this anisotropy as well as provide additional constraints on the age of the IC.

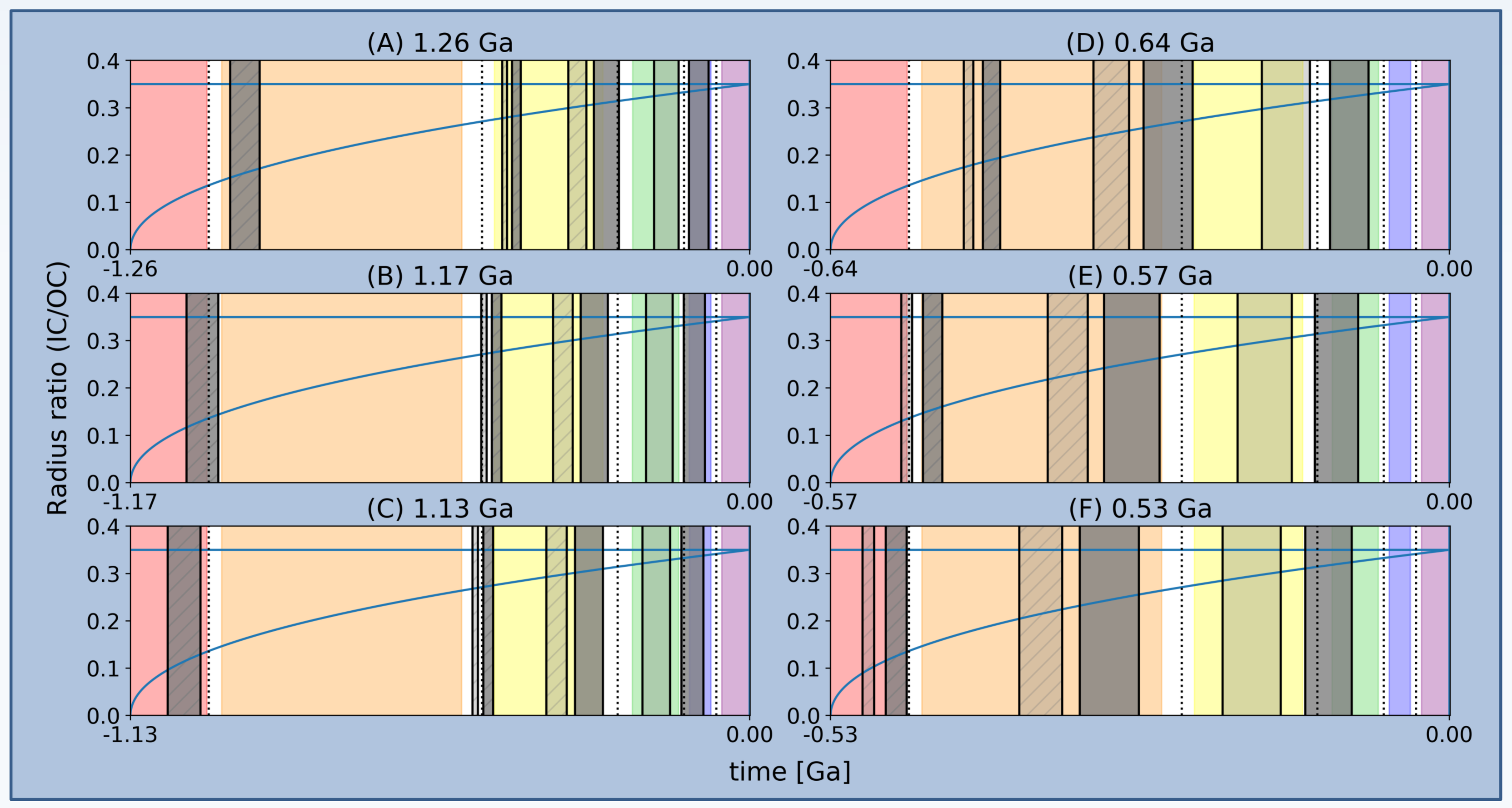

Figure 6: IC stratigraphy-models together with hyperactive periods and superchrons. (A) – (C) depict the first age range, 1.3 – 1.1 Ga where they overlap reasonably well. (B) is the best fit, while (A) and (C) show the end members of the range. (D) – (F) show another range with a good fit, namely 0.64 – 0.53 Ga. (E) is the best fitting model in this range. The time-axis is adjusted for each plot.

Acknowledgements:

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 681535 - ATUNE) and a Vici award number 016.160.310/526 from the Netherlands organization for scientific research (NWO). The facilities of IRIS Data Services, and specifically the IRIS Data Management Center, were used for access to waveforms, related metadata, and/or derived products used in this study

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