Inner core's seismic anisotropy is related to its rotation

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Abstract The inner core has a differential rotation relative to the crust and mantle, the relative linear velocity between the solid inner core and the molten outer core is the biggest at the equator and zero at pole area. As a result, the inner core grows faster at the equator than at the pole area. The gravitational force drives the material flow from the equator to the pole area and makes the inner core remain quasi-orbicular. The corresponding axial symmetric stress field makes *c*-axes of hexagonal close packed (hcp) iron align with inner core's rotation axis, resulting in observed seismic anisotropy.

Keywords: **inner core growth, rotation, viscous flow, preferred crystal orientation, anisotropy.**

Recent researches show that the inner core of the earth is axial symmetric seismic anisotropic (transverse isotropic), where seismic velocity propagating in the polar direction is faster than that in the equatorial direction by 3%[1—3]. The inner core's seismic anisotropy can be attributed to the preferred crystal orientation of the material which comprises the inner core. Previous high pressure and temperature experiments have presumed that the hexagonal close packed (hcp) iron (ε-phase) is the most likely phase at inner core conditions[4,5]. The hcp iron is axial symmetric anisotropic (transverse isotropic), P wave velocity would be faster along c-axis than perpendicular to it. If c-axes of all the hcp irons that compose the inner core are parallel to the earth's axis, it will result in the observed seismic anisotropy. Then, why have the hcp irons the preferred orientation? Generally, the crystals' fabric is determined by the physical and chemical phenomena, especially the stress field, during their growth[6]. The inner core's rotation around its axis may produce an axial symmetric stress field that leads to the axial symmetric anisotropic fabric in the inner core and at last results in observed seismic anisotropy.

1 The crystallizing growth of the inner core and the viscous flow in it

According to Song et al.[7] and Su et al.[8], we know that the inner core rotates faster than the crust and mantle. There is a differential rotation between the solid inner core and the molten outer core. At inner core's surface the relative linear speed is the fastest at the equator, and the slowest at the pole, which can be expressed by $\sin(\theta)$, while θ is the angle relative to the inner core's north pole. According to the theory on crystal growth from molten status, the crystal growth speed is proportional to the relative linear speed between the solid and the molten crystal[9]. So, as the solid inner core grows in the molten outer core, the growth is faster at the equator than at the pole, which can be expressed by $u = u_0 + u_r\left(\sin\theta - \frac{2}{\pi}\right)$, where u_0 is the average growth velocity of the inner core and u_r is a factor, and it can be developed to zonal spherical harmonics with only even order up to order 4. Ignoring harmonics with bigger orders results in errors not bigger than 2%. This growth mode will cause a platy, not orbicular, inner core. But the inner core is at high pressure and high temperature, and shows strong plasticity and viscous. Under the gravitational force, the inner core keeps quasi-orbicular, with a flow from the equator where the growth is faster to the pole area where the growth is slow, and results in an axial symmetric viscous flow[3] (fig. 1). At the inner core's boundary, the viscous flow velocity can be written as

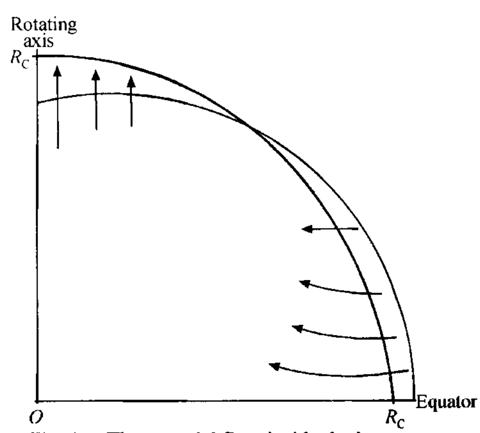

Fig. 1. The material flow inside the inner core.

$u = u_r\left(\sin\theta - \frac{2}{\pi}\right)$: at the equator crystallizing velocity is fast and the viscous flow velocity is positive, indicating the flow into the inner core; in the pole area crystallizing velocity is slow and the viscous flow velocity is negative, indicating the flow to the outer part of the inner core.

2 The stress field in the inner core

The above-mentioned axial symmetric viscous flow is surely accompanied by a rotational symmetric stress field[3]. We assume incompressible viscous deformation driven by the force balance between the viscous drag and the pressure gradient, namely, the Stokes' approximation:

$$-\nabla\left(\frac{p}{\rho}\right)+\nu\nabla^2 u = 0,$$

$$\nabla\cdot u = 0,$$

where ρ is the density, p is the nonhydrostatic pressure, ν is the kinematic viscosity, and u is the viscous flow velocity. We solve these equations using the standard toroidal-poloidal decomposition, but consider only the poloidal flow, which can also be expressed by the zonal spherical harmonics with orders up to 4, because the toroidal flow is not induced in the present problem. Consequently we can get the stress components σ_{rr}, $\sigma_{\theta\theta}$, $\sigma_{\phi\phi}$, $\sigma_{r\theta}$, the other two components are zero. Then we can get values and directions of the three principal stresses σ_1, σ_2, σ_3, and corresponding deviatoric stresses σ'_1, σ'_2, σ'_3 under the principal coordinate. Since the sum of σ'_1, σ'_2, σ'_3 under the principal coordinate should be zero, two of them have the same sign, and one has the opposite sign: two positive and one negative or two negative and one positive. As a result of the calculating here with all model parameters from ref. [3], in the inner core deviatoric stresses σ'_1, σ'_2 are in the plane perpendicular to the inner core's rotation axis and are compressive, when deviatoric stress σ'_3 is parallel to the inner core's rotation axis and tensile, except the very thin layer uppermost (fig. 2). This is actually similar to the material flow style and stress field in a cylinder under pressure and a relative tensile load parallel to its axis.

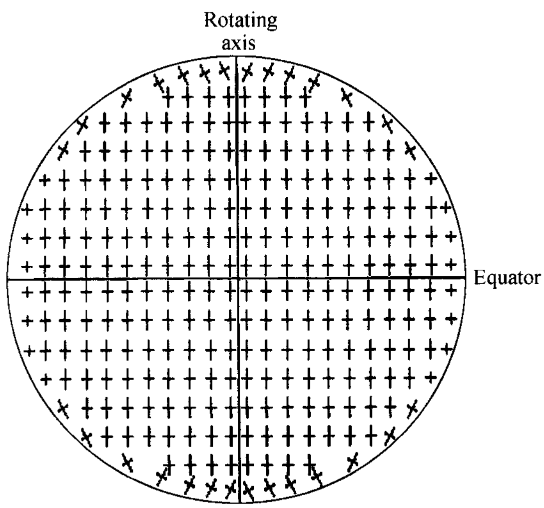

Fig. 2. The deviatoric stress field in the inner core. Long bar indicating tensile and short bar compressive deviatoric stress.

3 The preferred orientation of hcp iron and the anisotropy of the inner core

In the light of Kamb's theoretical analysis, c-axis of hcp iron tends to align with the axis of the principal pressure which has a sign different from the other two, in order to have the lowest elastic energy in the system[3,10,11]. So, in most parts of the inner core, c-axes of hcp iron align with the rotation axis, resulting in the observed seismic anisotropy.

4 Discussion

The axial symmetric seismic anisotropy is caused by the axial symmetric fabric, and the axial symmetric fabric is produced by the axial symmetric stress field, when the axial symmetric stress field is related to the rotational symmetric viscous flow and the rotational symmetric viscous flow results from the inner core's rotation around its axis. So the symmetric axis of the inner core's seismic anisotropy should coincide with its rotation axis. Song et al.[7] and Su et al.[8] have found that there is an angle of about 10.5° between the symmetric axis of the inner core's seismic anisotropy and the earth's axis, and this symmetric axis revolves around the earth's axis at a speed of about 1°—3°/a. Based on this, they deduced that the inner core rotates faster than the crust and mantle. According to our analysis in the present contribution, the symmetric axis of the inner core's seismic anisotropy should be its rotation axis, because it is hard to explain in physics that there is a angle of about 10.5° between the inner core's fabric symmetric axis and the earth's rotating axis if the inner core's rotating axis coincides with the earth's rotating axis. If it is true, the 1°—3°/a differential rotation observed by Song et al.[7] and Su et al.[8] maybe is not really the rotation of the inner core, and it should be the precession of the inner core's rotation axis relative to the outer earth. It is also questioned in ref. [7] if the inner core rotation axis tracks the north-south spin axis in the precession of the equinoxes. Su et al.[8] found that the angle between the inner core's symmetric axis of seismic anisotropy and the axis of the earth has an undulation with a period of about 8.39 a. This may be the nutation of the inner core's rotation axis along with the precession. Since the molten outer core is liquid with a coefficient of kinematic viscosity as low as 3×10^{-7}—$2\times10^{-5}\,m^2s^{-1}$[12], it is possible for the inner core to move almost freely inside the earth.

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