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THE GYRICITY OF THE EARTH*

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ABSTRACT

An introductory exploration of the mechanical influence of long-term gyricity or gyroscopic effect on the dynamics of the Earth is presented. Gyricity exists in a deformable, energy-dissipating, and thus rotationally unstable Earth in the form of internal torques, or the rate of change of angular momentum independent of external torques. The kinematics of the internal torques appear compatible with the gross features of the Earth's surface plate tectonics. The internal torques calculated bases on present observations do not balance with each other, but their secular components are all of the order of 10^{23} erg. Based on the history of polar excitation, the equation of secular motion in the Earth in the absence of external torques is derived under the law of conservation of angular momentum. The equation links the dynamics of polar instability with those of secular motions, notably plate motion and mantle flow, in the Earth. Gyricity is found to dominate the driving mechanism of the secular motions.

1. INTRODUCTION

We know from classical mechanics that the rate of change of a vector in a reference frame rotating relative to an inertial frame fixed in space differs from that in the inertial frame by a cross product of the angular velocity of the rotating frame with the vector. A direct result of this difference is the gyroscopic effect. This effect has long been known and put into application; however, gyrodynamics becomes important only in light of space dynamics (Thomson, 1963, p. 101-193).

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From the observation of orbiting of space vehicles, it has been discovered that the rotation stability of a space vehicle can be significantly affected by the gyroscopic effect if there is dissipation of energy in the vehicle (Thomson, 1963; Roberson, 1971; D'Eleuterio and Hughes, 1981, 1983; Hablani, 1982). D'Eleuterio and Hughes (1983) classify the gyroscopic effect, together with the inertial (mass), dissipative (damping), and stiffness (elastic) effects, as the four mechanical influences on the dynamics of flexible structures, and introduced the concept of gyricity. In this paper, however, gyricity is synonymous with the gyroscopic or gyric effect.

The Earth is a deformable, energy-dissipating, and perpetually rotating heavenly body orbiting in space. The rotation dynamics of the Earth are thus similar to, if not the same as, those of a space vehicle. The fundamental mechanical influences on the dynamics of the Earth therefore include gyricity or the gyric effect. The Coriolis acceleration is such an effect. However, the Earth has, in a secular sense, an additional mechanical influence that a space vehicle does not show in its life time. This is viscoplasticity or rheology. The Earth's long-term gyricity is thus gyro-viscoplastic rather than gyro-elastic such as that in a space vehicle (D'Eleuterio and Hughes, 1983).

Any motion in the Earth, instantaneous or secular, will be subject to the effects of gyricity. The well-known gyricity observed on the Earth is the Coriolis force, which is known to be negligibly small and thus led to the conventional belief that Coriolis acceleration plays a very small role in geodynamics. This is indeed the case in an instantaneous sense, but not in a secular sense. Observations (Rance, 1968, 1969; Howell, 1970) suggest that the torsional deformation of the tectonic features on the ocean floors, such as the major physiographic lineaments and transform faults, may be attributable to the Coriolis effect. The rotational inertia of the continents also belongs to this effect (Kane, 1972). The recently observed "vertical axis rotation" of the crustal blocks (Hudnut, 1991; Argus and Gordon, 1991) may also be due to gyricity. Pan (1975, 1983, 1985) has calculated the (secular) Coriolis torque in the Earth and observed that the gross features of the present plate tectonics, such as plate distribution, plate motion, the spread of oceanic ridges, and the subduction of the oceanic slabs, all reflect the *quadrupolar* nature of the Coriolis torque. This suggests that the secular Coriolis acceleration or long-term gyricity may well be the primary driving mechanism for plate motion and mantle flow (Pan, 1985). This paper is an introductory exploration of the dynamic effects of the long-term gyricity, or the gyricity arising from secular motions—notably secular polar shift, plate motion, and mantle flow—to the Earth, under the law of conservation of angular momentum.

2. THE LIOUVILLE EQUATION AND GYRICITY

Gyricity becomes dynamically influential only in a deformable, energy-dissipating, and thus rotationally unstable Earth (Pan, 1993). The Earth's rotation or polar instability has been studied using the Liouville equation (Munk and MacDonald, 1960, p. 9-10; Lambeck, 1980, p. 33-36; Moritz and Mueller, 1988, p. 122-124). The Liouville equation is a generalized Eulerian equation of motion which allows for motion in the rotating system. The equation states that the rate of change of the total angular momentum of a rotating system is equal to the external torques exerted on the system. The rate of change of angular momentum is, therefore, a reaction of the rotating system to the external torques, and can thus be called the internal torques of the system (Pan, 1975, 1978, 1983, 1985). In the absence of external torques, the law of conservation of angular momentum requires that the rate of change of the total angular momentum of a system must be zero. However, the rate of change of angular momentum or the internal torques are observed to exist in the Earth independent of external torques. These internal torques must be, therefore, arising due to mass redistribution within the Earth (Pan, 1975, 1978, 1983, 1985, 1993).

Let **I** designate the inertia tensor of the Earth, ω be the Earth's rotation velocity, and **h** be the relative angular momentum arising due to mass redistribution within the Earth, which, as shown by Pan (1975, 1982, 1985, 1993), consists of two terms, that arising due to motion and that involving the products of inertia induced by the motion. Designating the Earth's axes of instantaneous moments of inertia to be the reference frame (x,y,z), then, in the absence of external torques, the Liouville equation in the (x,y,z) frame rotating relative to an instantaneously coinciding inertial frame fixed in space is

$$\dot{\mathbf{I}}\cdot\omega + \mathbf{I}\cdot\dot{\omega} + \dot{\mathbf{h}} + \omega \times \mathbf{I}\cdot\omega + \omega \times \mathbf{h} = \mathbf{0} \tag{1}$$

where ($\cdot$) designates *d/dt* relative to the *(x,y,z)* frame. The left-side terms in Eq. 1 represent the rate of change of the Earth's total angular momentum, or the internal torque system of the Earth. These internal torques represent all the central-force dynamics in the Earth in the absence of external torques (Becker, 1954, p. 162 and 165). Of the five terms, three belong to gyricity; the first, fourth, and fifth terms are gyric torques.

The first term $\dot{\mathbf{I}}\cdot\omega$ arises from the change in the moment of inertia in response to the angular momentum perturbation. This is not a typical gyric torque that can be represented by the cross product of with velocity. However, as Pan (1975, 1978, 1983, 1985) has demonstrated, this term belongs to gyricity because it arises from secular motions in a rotating Earth. It is called the Coriolis torque and has a magnitude on the order of 10^{23} erg, which, if converted to force exerted at the bottom of the lithosphere, is about 12 to 80 times greater than the extensional force exerted at the same location by upper mantle convection (Richter, 1973). Pan (1985) has also shown that kinematically this gyric torque consists of two components, lateral and radial, and is *quadrupolar*. That is, based upon the three-finger rule of the right-handed system, its components are opposite in opposite hemispheres, depending upon the direction of secular polar shift or lateral motion in the hemisphere. The quadrupolar nature of this gyric torque could be responsible, as shown in Fig. 1, for the breakup of the lithosphere in about 90° plates, as well as the westward subduction of the Pacific plate in the northern hemisphere, and the eastward subduction of the same plate in the southern hemisphere. Near the equator and without the confrontation of a continental plate, the quadrupolar effect of the torque becomes a little chaotic and the confronted oceanic plates may go down in both directions, such as those near the Hebridges, Fiji, and Tonga Islands. More detailed calculation and analysis of this gyric torque can be found in Pan (1985).

The second and third terms in Eq. 1 are the two components in the Earth's internal torque system that have nothing to do with gyricity. The second term $\mathbf{I}\cdot\dot{\omega}$ arises from rotational acceleration and can thus be called the rotational torque (Pan, 1985). Using the Earth's instantaneous moments and products of inertia and their rates of change calculated by Pan (1982, Tables 1 and 2), as well as the Earth's present mean rotation speed $7.292\mathrm{x}10^{-5}$ rad/sec and observed rotational accelerations (Markowitz, 1970, 1972; Lambeck, 1977; Lambeck and Cazenave, 1973, 1977; Morrison, 1978), the different components of the torque are calculated and listed in Table 1, where β denotes the azimuth angle of the Earth's rotation axis. The calculation procedures can be found in Pan (1985, Appendix). This internal torque has, as shown in Table 1, diverse components, some of which are due to external causes. The periodic and irregular components are on the order of 10^{26} erg, while the secular component is on the order of 10^{23} erg. The secular component of the torque is presumably due to tidal friction (Munk and MacDonald, 1960; Jeffreys, 1962; Markowitz, 1970; Lambeck, 1975, 1977), but the effects of the oceanic tides cannot totally account for the secular component of $\dot{\omega}$ (Munk and MacDonald, 1960; Lambeck, 1975, 1977; Morrison, 1978). The non-tidal secular component of $\mathbf{I}\cdot\dot{\omega}$ is of the same order of magnitude as that of $\dot{\mathbf{I}}\cdot\omega$, 10^{23} erg, and can be called the secular rotational torque. The secular rotational torque acts toward the north; it may be responsible for northward plate motion such as the collision of the India plate with the Eurasia plate, the subduction of the Cocos subplate underneath Middle America, the subduction of the Pacific plate underneath the Aleutian arcs and Alaska, etc., as shown in Fig. 1. There is no southward subduction observed in the Earth.

The third term in Eq. 1 $\dot{\mathbf{h}}$ is the rate of change of the relative angular momentum. Pan (1975) calls it the relative *disturbing* torque. It may play an important role in initiating polar excitation. Its magnitude is dependent upon the perturbating acceleration and the rate of change of the products of inertia, as well as the mass involved in producing the relative angular momentum. Pan (1975) calculated that this torque is also on the order of 10^{23} erg, the same as $\dot{\mathbf{I}}\cdot\omega$ and $\mathbf{I}\cdot\dot{\omega}$. However, it can reach a much higher magnitude, but only in a transient sense. For instance, the magnitude of $\dot{\mathbf{h}}$ arising from the impact of a giant asteroid or comet can reach as much as 10^{28} erg if the asteroid is of the size suggested by Alvarez and Asaro (1990).

The fourth and fifth terms in Eq. 1 are typical gyric torques, and also are the least studied. The fourth term $\omega \times \mathrm{I} \cdot \omega$ arises from the slight separation of the Earth's angular momentum axis and the instantaneous figure axis. The magnitude of this gyric torque is listed in Table 2. This gyric torque is the largest internal torque in the Earth; the only other internal torque that is able to reach a comparable magnitude is the relative disturbing torque $\dot{\mathbf{h}}$, but $\dot{\mathbf{h}}$ is only transient, while $\omega \times \mathrm{I} \cdot \omega$ is periodic. As listed in Table 2, the magnitude of this gyric torque is dependent upon the Earth's axial near-symmetry and triaxiality. In an axially near-symmetrical and slightly triaxial Earth, this torque is at least 6 orders of magnitude greater than any other internal torque in the Earth. If the Earth is biaxial, then the z-component of this gyric torque becomes zero, but its x- and y-components are still greater than those of any other internal torque in the Earth. It is unlikely that this torque can be totally accounted for by external causes. The interpretation of this gyric torque under the law of conservation of angular momentum is a major concern in the study of the dynamics of the Earth.

The fifth term in Eq. 1 $\omega \times \mathbf{h}$ arises from the motion or mass redistribution in a rotating Earth. Any motion in the Earth will induce such a gyric torque, with its magnitude dependent upon the relative angular momentum **h**. Based on the three-finger rule of the right-handed system, this gyric torque is circulative. That is, a lateral motion will induce a radial torque, while a radial motion will induce a returning lateral torque. For instance, the lateral motion of a tectonic plate will induce a radial gyric torque towards the interior of the Earth, while a subduction will induce a returning lateral flow in the interior. On the other hand, lateral motion in the interior will induce an upward flow, while an uprising plume will induce a lateral gyric torque on the surface. The migration of hot spots such as is observed along the Hawaiian island chain may belong to such an effect. Mantle convection, if it indeed occurs in the interior, will also be subject to this gyric torque. Pan (1985) calculated that a $\omega \times \mathbf{h}$ arising from the motion of a tectonic plate is on the order of 10^{22} erg, and is toward the center of the Earth. Only a $\omega \times \mathbf{h}$ arising from whole mantle convection will be able to reach the orders of magnitude of the Coriolis and secular rotational torques, 10^{23} erg.

Reference frame is critical to the calculation of the internal torques of the Earth. Munk and MacDonald (1960, p. 10-14) point out that, because of the Earth's non-rigidity, finding a truly body-fixed frame in the Earth is unlikely. Reference frames such as the *Tisserand* and the *principal axes* were the obvious choices for mathematical simplicity. Chao (1984) further examines reference frames, including Smith's (1977) invariant frame, and points out that there is an inconsistency between the reference frame used for observation and those used for theoretical calculation. On the other hand, Pan (1993) discusses the inadequacy of Munk and MacDonald's (1960, p. 10-14) geographic frame, and then chooses the (x,y,z) frame of this paper. In order to make it physically meaningful, the frame is made geocentric, with its z-axis aligned with the *axis of reference* (Munk and MacDonald, 1960, p. 5) or the *geographic axis* (Smith, 1977) around which the rotation axis revolves. The y-axis is chosen to be in the direction of secular polar shift, while the x-axis is perpendicular to the y- and z-axes in the right-handed system. Such a reference frame is physically located in the Earth and is always associated with polar motion, including polar wandering. This reference frame has thus avoided the physical uncertainty or discrepancy that the conventional reference frames have encountered. The calculation in this paper is, therefore, valid at least in an order-of-magnitude sense.

3. CONSERVATION OF ANGULAR MOMENTUM

From the above discussion of the Earth's internal torques, we can see that they are ***not*** totally balanced as predicted by Eq. 1. This is not really surprising, since our understanding of the Earth's dynamics is still quite limited. Some of the various components of the internal torques may be due either to non-central-forces or external causes which we have not yet discovered. Among these internal torques, the periodic and irregular components of the rotational torque $\mathbf{I} \cdot \dot{\omega}$ are least understood. However, they are not of much concern in this paper because of their short time scales. Our major concern here is the fourth term in Eq. 1 $\boldsymbol{\omega} \times \mathbf{I} \cdot \boldsymbol{\omega}$ which is several orders of magnitude greater than any other internal torque in the Earth. It is unlikely that this gyric torque will be balanced by some yet-to-be-discovered external torque. Then, if the law of conservation of angular momentum is not violated, this torque must be balanced in some way within the Earth, such as by the mantle-core coupling (Flodmark, 1991a, 1991b). Otherwise, the present rotation velocity of the Earth is much too high, and yet it is secularly accelerating. However, it is interesting that all the secular components of the internal torques are of the same order of magnitude, 10^{23} erg. This implies that we can at least work out the conservation of the Earth's angular momentum in the absence of external torques in a secular sense using presently available observations.

Pan (1985) demonstrates that polar instability, plate motion, and mantle flow are interrelated, and that such an interrelation may trace back to the evolution of polar excitation. From there, an equation of secular motion in the Earth was preliminarily derived under the law of conservation of angular momentum. Here we may rederive the equation in a more refined way. If we assume that, prior to the first polar excitation in geological history, the Earth was rotating in a stable state of minimum energy configuration; i.e., the rotation axis was completely aligned with the principal axis, and the rotation was constant. Then, let $\mathbf{I}_0$ be the constant inertia tensor of the Earth with this minimum energy configuration, and $\boldsymbol{\omega}_0$ be the constant rotation velocity. The law of conservation of angular momentum requires that

$$\mathbf{I}_0 \cdot \boldsymbol{\omega}_0 = \text{Constant}. \tag{2}$$

On the other hand, let **h** be the relative angular momentum that suddenly appears in the Earth due to motion or mass redistribution occurring within the Earth. The Earth's inertia tensor will then correspondingly change to a variable **I**, and the rotation velocity to a variable $\boldsymbol{\omega}$. At this very moment, say t = 0, the conservation of angular momentum requires a transfer of the Earth's angular momentum from a minimum energy configuration to an excited configuration with a higher energy budget; i. e.,

$$\mathbf{I}_0 \cdot \omega_0 = \text{Constant} = \mathbf{I} \cdot \omega + \mathbf{h} \ . \tag{3}$$

Applying the differentiation operator *d/dt* + $\omega \times$ to Eq. 3, the rate of change of the Earth's total angular momentum independent of external torques *in* the *(x,y,z)* frame, rotating relative to an instantaneously coinciding inertial frame fixed in space, at this moment of transition is

$$\omega \times \mathbf{I}_0 \cdot \omega_0 = \mathbf{0} = \dot{\mathbf{I}} \cdot \omega + \mathbf{I} \cdot \dot{\omega} + \dot{\mathbf{h}} + \omega \times \mathbf{I} \cdot \omega + \omega \times \mathbf{h} \tag{4}$$

where both $\mathbf{I}_0$ and ω_0 are constant with respect to time.

The terms in the middle and on the right-side of Eq. 4 are identical to Eq. 1, and the left side of the equation, $\omega \times \mathbf{I}_0 \cdot \omega_0$, is practically equal to zero. Physically this left side means that, at the incipient moment of polar excitation, there is a transfer of the angular momentum from the stable rotation of a minimum energy configuration to an unstable rotation in an excited configuration. At this moment of transition, we can imagine that there exist simultaneously two angular momenta in the Earth. One is an instantaneous "frozen" remnant about the original principal axis, and the other appears with the unstable rotation about the "instantaneous figure axis," which has been shifted away from its original alignment with the principal axis due to the appearance of **h** (Pan, 1993). The remnant angular momentum will be transferred totally to the "instantaneous figure axis" immediately afterwards. Equation 4 then becomes identical to Eq. 1. The term $\omega \times \mathbf{I}_0 \cdot \omega_0$ in Eq. 4 is therefore practically an initial condition for polar excitation.

4. THE EQUATION OF SECULAR MOTION IN THE EARTH

After the initial condition for polar excitation has been fulfilled, we may neglect all the non-secular terms in Eq. 4 and relax the assumption about the time of incipient polar excitation. We add the suffix s to all the secular terms in Eq. 4 and let $\mathbf{I}_0 \cdot \omega_0$ represent the "fossil" angular momentum of the Earth in a *completely* stable rotation of minimum energy configuration. Then the equation of secular motion in the Earth is (Pan, 1985)

$$\dot{\mathbf{I}}_s\cdot\omega_s + \mathbf{I}_s\cdot\dot{\omega}_s + \omega_s\times\mathbf{h}_s = \omega_s\times(\mathbf{I}_0\cdot\omega_0 - \mathbf{I}_s\cdot\omega_s). \tag{5}$$

All the terms in Eq. 5 belong to the gyric effect except the second term at the left-side of the equation, the secular rotational torque. The equation suggests that gyricity dominates the driving mechanism of secular motions in the Earth.

The left side of Eq. 5 represent the driving mechanism for secular motions in the Earth which have already been discussed in a rather general and kinematic sense. The secular Coriolis torque $\dot{\mathbf{I}}_s\cdot\omega_s$ and the secular rotational torque $\mathbf{I}_s\cdot\dot{\omega}_s$ represent the Earth's damping of the products of inertia for a stable rotation of minimum energy configuration through slow mass redistribution and gradual rotational deformation. Whereas, $\omega_s\times\mathbf{h}_s$ is a gyric torque responding to the secular motions induced by the Coriolis and secular rotational torques, which consequently enhances the secular motions. Pan (1985) gives a more detailed analysis of these secular internal torques in the Earth, as well as their effects on plate motion and mantle flow.

The right side of Eq. 5 is a correction for polar stability; it is a driving mechanism for the Earth to reach its stable rotation of minimum energy configuration through elimination of polar motion. It is namely the "ass-and-carrot" pursuit of the "instantaneous figure axis" after the rotation axis, and the principal axis after the "instantaneous figure axis" (Gold, 1955; Munk and MacDonald, 1960, p. 265-75; Pan, 1983, 1985, 1993). The magnitude of this term is equivalent to the excess rotational energy gained at polar excitation which must be dissipated in order for the Earth to reach a stable rotation of minimum energy configuration. It is equal to the magnitude of the resultant of the secular internal torques in the Earth; i. e., on the order of 10^{23} erg, which is negligible comparied to the Earth's total rotational energy of about $2.16\text{x}10^{36}$ erg. The above estimate, however, is only of order of magnitude, since it is still difficult to determine the magnitude of the "fossil" angular momentum $\mathbf{I}_0 \cdot \omega_0$ from present observations. Moreover, as Pan (1993) points out, the present physical location of the Earth's principal axis is yet to be determined. This raises the difficulty of accurate determination of the Earth's instantaneous moment of inertia.

Equation 5 exhibits a dynamic linkage between polar instability and secular motions in the Earth. For a stable rotation of minimum energy configuration, the Earth must dissipate the excess rotational energy gained at polar excitation to let its angular momentum approach an equilibrium value; i. e., $\mathbf{I}_s \cdot \omega_s \rightarrow \mathbf{I}_0 \cdot \omega_0$ to make the right side of Eq. 5 go to zero. In order to reach such an equilibrium, the secular variations of the Earth's moment of inertia and rotation must cease or balance each other; i. e., $\dot{\mathbf{I}}_s \cdot \omega_s + \mathbf{I}_s \cdot \dot{\omega}_s \rightarrow \mathbf{0}$. Also, the secular relative angular momentum in the Earth must cease such that $\omega_s \times \mathbf{h}_s \rightarrow 0$. In other words, in order to reach a complete rotation stability of minimum energy configuration, the right side of Eq. 5 must go to zero. This occurs through the actions of the secular internal torques, $\dot{\mathbf{I}}_s \cdot \omega_s$, $\mathbf{I}_s \cdot \dot{\omega}_s$, and $\omega_s \times \mathbf{h}_s$, damping the products of inertia via slow mass redistribution and gradual rotational deformation, which then force the "instantaneous figure axis" to nutate and follow the rotation axis, while the principal axis is dragged along to pursue after the "instantaneous figure axis." This is polar motion. The nutation is the Chandler wobble, and the pursuit among the axes constitutes secular polar shift.

5. DISCUSSION

This paper introduces only a preliminary exploration of the dynamic effects of long-term gyricity and other internal torques in the Earth. The discussion centered around the terms in the Liouville equation independent of external torques, and the Earth was treated almost equivalent to a rotating system of particles moving among themselves in response to the actions of central forces under the law of conversation of angular momentum. The dynamics are discussed only in general and order-of-magnitude terms. What roles the other non-rigidity effects in the Earth, such as the elasticity, viscoplasticity, buoyancy, etc., will play under the influence of gyricity and other internal torques is an important subject that has not yet been studied. These effects, however, can be easily integrated into the Earth rotation model used in this paper. Pan (1993) demonstrates that motions in individual layers in the Earth, such as the fluctuation of the atmosphere, currents in the oceans, flows in the mantle and liquid outer core, and even tectonic movements and mantle convection, can be easily incorporated into the model through the definition of the relative angular momentum for each layer. Such an integration of layered motions is not achievable using the conventional models based on the rotation of a rigid body (Smith, 1977; Wahr, 1981a, 1981b, 1981c, 1982, 1983; Moritz and Mueller, 1988, p. 131-179, and 204-279).

Pan (1985) studies the behavior of the Coriolis and secular rotational torques in the mantle and names the torque-induced flow in the mantle the *transvection*, while *convection* is reserved for flows of thermal origin. Thermal convection in the mantle has long been believed to be the driving mechanism for plate tectonics. However, the uncertainty concerning the physical properties in the Earth's interior presents an obstacle to the various models of mantle convection. Mantle convection models are generally divided into four categories: thermal plumes (Morgan, 1971; Olson and Singer, 1985), upper mantle convection (Richter, 1973, 1979; Nakada, 1983; Fleitout and Yuen, 1984), layered or two-layer convection (Marsh and Marsh, 1976; Sammis, 1976; Kenyon and Turcotte, 1983; Richards and Hager, 1984; O'nions, 1987), and whole mantle convection (Sammis, 1976; O'Connell, 1977; Elsasser et al, 1979; Richards and Hager, 1984). The effect of the Earth's rotation, particularly the long-term gyricity, has hardly been considered in the various models of mantle convection. Convection currents, if they indeed occur in the mantle, will certainly be affected by gyricity like other secular motions in the Earth. Preliminary calculations in this paper indicate that the driving effects of upper mantle convection can be one order of magnitude smaller than those due to transvection, and only the convection involving the whole mantle is able to induce a circulative gyric torque with a magnitude on the order of that of the Coriolis and secular rotational torques. This implies that if thermal convection were the driving mechanism for plate motion, it would be a whole mantle convection. Using the Earth rotation model developed by Pan (1993), the Earth's rotation effect can easily be integrated with thermal convection through the relative angular momentum of the mantle. The relationship between thermal convection and the torque-induced transvection in the mantle, as well as the effects of the secular internal torques on convection, are worth further investigation.

6. CONCLUSIONS

Gyricity is one of the four fundamental mechanical influences on the dynamics of a deformable and energy-dissipating Earth. In the absence of external torques, gyricity exists in the Earth in the form of internal torques. All motions in the Earth, instantaneous or secular, would be under the effect of gyricity. The equation of secular motion links the dynamics of polar instability or long-term gyricity with those of secular motions, notably plate motion and mantle flow, in the Earth. Polar motion represents the Earth's attempt to dissipate the excess rotational energy gained at polar excitation in order to reach a stable rotation of minimum energy configuration; i. e., the effort for the Earth to reach a complete alignment of its rotation axis, "instantaneous figure axis," and principal axis. The Coriolis and secular rotational torques represent slow mass redistribution and gradual rotational deformation in the Earth to damp the products of inertia for a stable rotation of minimum energy configuration, while responding gyric torques will enhance such secular adjustments for polar stability. Gyric torques dominate the driving mechanisms of the secular motions in the Earth, which, together with the secular rotational torque, may well be the primary driving mechanisms for plate motion and mantle flow. Thermal convection, if it occurs in the mantle, would have to be a whole mantle convection.

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LIST OF FIGURES

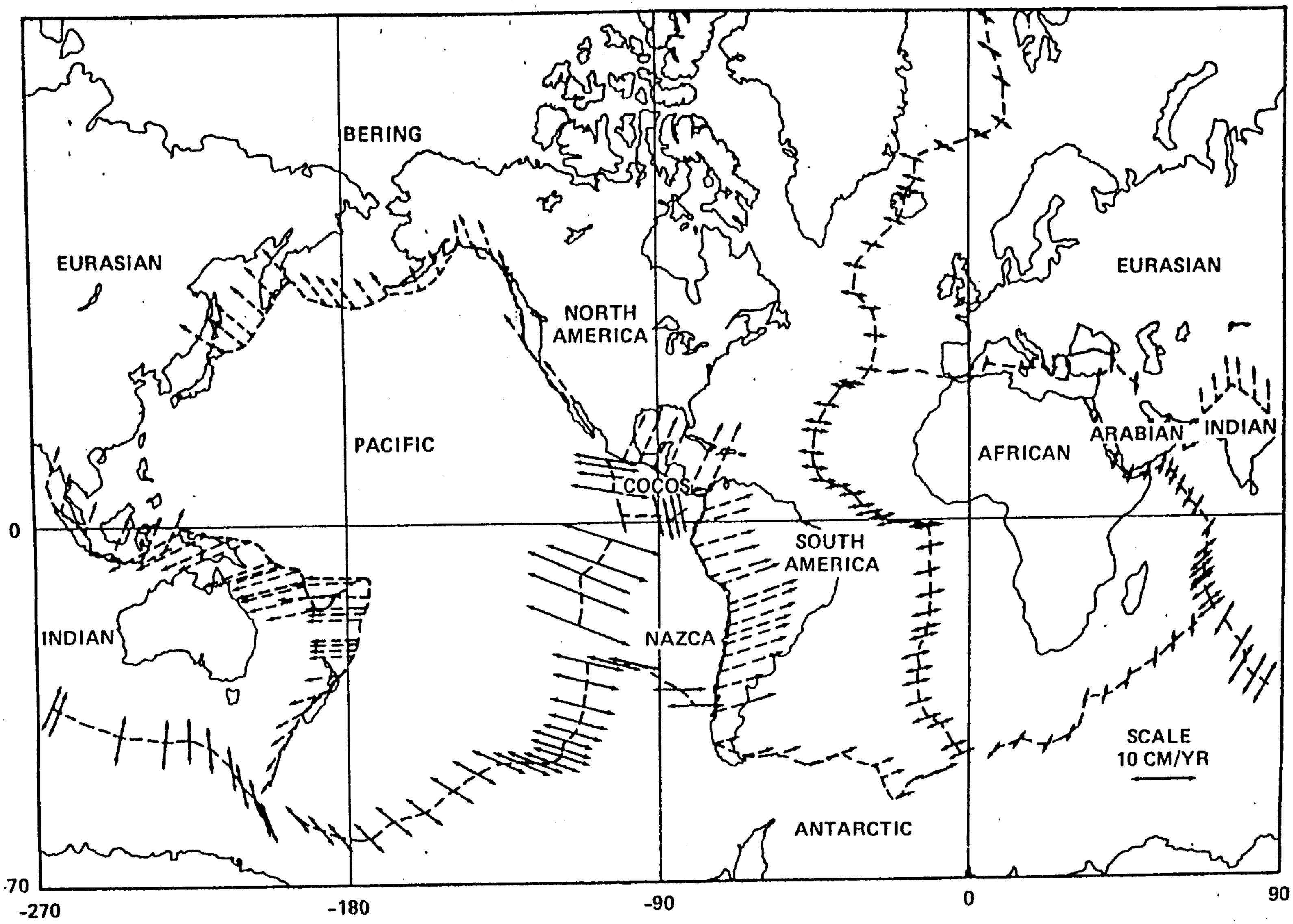

Figure 1. The present plate tectonics (after Minster et al, 1974).