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A Study on the Plate Tectonics in the Early Earth Period Based on the Core-Magma Angular Momentum Exchange

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Abstract

By using a dynamical approach of core-magma angular momentum exchange, this study theoretically explains the continental formation and plate drift as well as main mountain uplifts in the early Earth period. The present mantle and lithosphere were the partial part of magma fluid layer (mantle currents) before and after the Earth's crust formation. Thus, a theory is presented regarding the driving forces of plate drift, in the form of planetary scale mantle currents. The origin of mantle currents is traced back to the formation of the solar system. It is assumed that small particles (nebula matter) orbiting the Sun assembled, and a molten sphere of primordial Earth with different minerals evenly distributed throughout the total mass came into existence. Subsequently, a process called planetary differentiation took place, as the core and mantle currents (magma layer) started separating. This will inevitably cause the Earth to spin faster, and it is presumed that the inner core first gained angular velocity, thereby spinning faster than the material found at a shallower depth. The time interval of the angular momentum exchange between the core and the magma should have lasted for at least 0.1 - 0.2 billion years. Planetary scale vertical and horizontal circulations of mantle currents took place, and angular momentum exchange was realized through the vertical component. The horizontal part of the mantle currents, near the bottom of the lithosphere, became a real force to drive continental split and plate drift. The acceleration and deceleration of the core compared with the mantle currents then caused different flow directions in the two hemispheres. When the inner core rotates faster from west to east, upper mantle currents will tend to flow westwards and towards the two poles. Surface lighter materials converged towards the two poles so that two continental polar crust caps appeared when the magma surface was cooling. This caused two original supercontinents to form about 4.54 billion years ago, while an original oceanic zone formed in the tropics. The uneven latitudinal variation of crustal thickness did lead to thermal differences within the mantle currents. This caused the core-magma angular momentum exchange. Deceleration of the core will cause two flow vectors, northwesterly in the Northern Hemisphere and southwesterly in the Southern Hemisphere. The history of plate drift is then driven by the motion of upper mantle currents. A distinct Equatorial Convergence Zone of magma flow which developed early in Earth's history, gave way to the Intertropical Convergence Zone, serving as a border for the magma fluids and continents from the two hemispheres. A possible mechanism for the formation of the Himalayans is the maximum shear stress created by an orthogonal convergence or collision between two continental plates driven by the upper mantle currents.

Keywords

Continental Formation, Plate Drift, Himalayans, Orthogonal Convergence, Intertropical Convergence Zone

1. Introduction

In scientific research of the solid Earth, from evidence descriptions or record collections to form various theories, the final goal is to establish a capable numerical model that can successfully simulate and predict the activities from the crust to deep layers of the Earth. In the last five decades, there is the geological controversy between plates and plumes [1]. The plume hypothesis describes heat flow rising from the deep mantle and is a local heating that can explain local volcanic activity on volcanic chains. Radioactive decay may produce local geothermal energy. Related studies have focused on the influence of radiative minerals in the Earth's interior on mantle plumes, which are local scale or regional scale dynamic processes [2] [3]. Plate tectonics describes the regional scale floating and movement of rigid plates on the semi-fluid asthenosphere below. But there is no answer to what force drives the semi-fluid asthenosphere. Volcanic chains are also a regional scale plume phenomenon. However, there is currently no theory explaining what forces cause these local scale and regional scale geological formations.

Some researches related to the Earth's activities are mainly associated with the mantle convections for local disaster events such as earthquakes and volcano eruptions [4] [5]. Since vertical mantle convection is locally associated with global tectonics [6], three-dimensional model of mantle convection with deformable and mobile continental lithosphere is desired [7]. Some three-dimensional models were developed to simulate the interactions between the mantle, lithosphere, and crust by using self-consistent generation of tectonic plates, a characteristics-based marker-in-cell method, and a finite element code for 3-D spherical convection [8] [9] [10]. Other models and dynamics considered the interaction of multiple circle layers linking the angular momentum exchange between the inner core and the mantle [11] [12] [13]. However, their angular momentum exchanges were based on gravitational coupling and tidal dissipation on a short-term scale. For example, angular momentum fluctuations were used to estimate the decadal fluctuations of the length of the day [14].

In the world, severe seismic hazards caused by earthquakes and volcanic activities are directly related to the local lithosphere movement. There is a major earthquake zone with severe seismic hazards extended from Java to Sumatra through the Himalayas and the Mediterranean [15] [16] [17] [18]. Another most active zone of earthquakes is the circum-Pacific belt, particularly along the Andes [19] [20] [21]. Why did so many strong earthquakes happen locally but concentrate along continental scale boundary zone? Some statistical methods such as deep learning and seismological and geological tools have been testily used in earthquake prediction [22] [23]. In practice, however, it is still extremely difficult to predict the lithosphere movement which causes earthquakes and volcano activities due to the lack of successful dynamical frameworks or methods including multiple-layer and multiple-scale interactive dynamics from the planetary scale to continental scale and local convective scale.

This study is one of many attempts to establish such a dynamical theory from multiple layer interactive point of view for the early Earth period. The idea is based on the interaction between the outer magma fluid layer and the inner solid core through angular momentum exchange by applying the Earth fluid motion equations (similarly to those used in atmospheric and oceanic sciences) to the magma fluid in that early period. Unlike other dynamical studies, this work focuses on geohistorical aspect of a very long-term scale, for explaining the continental drift and mountain formation, as well as the present global complex plate tectonics. It is hoped that this dynamical theory can be developed further, such as combined with other short-term and local scale models mentioned above, to be able to comprehensively simulate the Earth plate movement in all temporal and spatial scales and accurately predict earthquakes and volcano activities in the future. An "orthogonal collision" concept was also discussed to explain the uplifting forces behind the major east-west oriented mountain formation such as the Himalayans.

The Himalayans are the highest east-west oriented mountain in the world, with a main peak of 8849 meters above sea level. A basic idea for the formation of this mountain range is the horizontal collision between the Indian plate and the Asian continent [24] [25] [26] [27], or an Archean continental collision [28]. In the vertical direction, the collision between adjacent plates not only formed the uplift of mountains but also caused the subduction of continental plates, meaning that the upward uplift and the downward extension of plates appeared nearby at the same time during the collision period [25] [29] [30] [31]. The content of this phenomenology is the geological trace left by the continental drift.

However, a dynamical explanation of driving continental drift on a global scale and what vertical force uplifting the oriented Himalayans are still missing.

The present understanding of mountain formation is an extension of earlier stories of continental drift and speculations from topography. As early as 1620, Francis Bacon, an English philosopher proposed the possibility of connecting the Western Hemisphere with Eurasia and Africa [32] [33]. At the end of the 19th century, the Austrian geologist Eduard Suess noted that the rock formations on the continents of the Southern Hemisphere were uniformly consistent so he proposed a single ancient continent of Gondwana in 1861 [34]. A famous scientist, Wegener from German proposed a theory of continental drift based on evidence from multiple disciplines [35]. His theory was comprehensively based on geological, geographical, paleontological, and paleo-climatological phenomena [36] [37]. Wegener studied astronomy at college and worked in meteorology after his graduation, while his preferred field of research was geology. As an enterprising meteorologist, looking at the terrain on weather maps every day, he had to ask about the possible formation of lands and oceans as well as the uplift of mountains because they affect the distribution of weather and climate.

The theory of continental drift has long been questioned by many geologists [38] [39]. Nor was Wegener able to explain what forces caused continents to drift on a planetary scale and what mechanism formed the highest Himalayas. With the development of paleomagnetism in the 50 s - 60 s of the 20th century, new evidence of continental drift was found in the sedimentary geomagnetic record of mid-ocean ridges [40] [41] [42] [43]. To explain observed evidence, dynamical theory of continental drift is needed. Continental drift mechanics must explain both global continental split and planetary scale drift as well as humongous vertical forces for uplifting major mountains like the Himalayans. The goal of this paper is to establish a dynamical theory of planetary scale continental formation and regional scale plate tectonics to answer these issues.

The paper is organized as follows. A dynamical framework for the plate tectonics of the early Earth is derived for the planetary scale movement of magma fluids in Section 2. In Section 3, the dynamical framework is used to explain the historical continent drift. In Section 4, the concept of "orthogonal collision" has been used to explain the powerful uplifting forces behind the mountain formation. Based on the theoretical foundation established in Sections 3-4, the present distribution of continents (mountains) and oceans on the Earth's surface is explained in Section 5, followed by conclusions in Section 6 and a discussion in Section 7.

2. A Dynamical Framework of Planetary Scale Movement of Magma Fluids

The oldest crustal age observed on the Earth is about 4.54 billion years [44]. Prior to this, the Earth was in an astronomical evolutionary stage. During that stage, the formation of original Earth's iron-rich cores generally occurred very early in planetesimals, the building blocks of proto-Earth, within about 3 million years [45]. The terrestrial planetary accretion involved violent and energetic giant impacts among different-sized objects and planetary embryos. Because of the impact heating, the early Earth was at times partially or wholly molten, increasing the likelihood for high-pressure and high-temperature equilibration among core- and mantle-forming materials. At the end of the Earth's astronomical evolution, the inner solid core and the outside molten magma layer became a conservation system of angular momentum because no materials entered the Earth from sky. In the early stage, melting would have caused denser substances to sink toward the center in a process called planetary differentiation, while less-dense materials would have migrated to the outside magma fluid layer. The conserved angular momentum of the system can be written as,

$$\Delta\left(I_c\Omega_c + I_m\Omega_m\right) = 0. \tag{1}$$

Here $\Delta = \dfrac{\mathrm{d}}{\mathrm{d}t}$, the two variables $I_c = \sum_i^c m_i r_i^2$ and Ω_c are the moment of inertia and rotation rate (or angular velocity) of the core, m_i and r_i are the mass and radius of a particle or an element inside the core. Similarly, I_m and Ω_m are the moment of inertia and the rotation rate of the entire outside magma fluid layer.

By expanding Equation (1), it becomes,

$$\Delta I_c \cdot \Omega_c + I_c \cdot \Delta\Omega_c + \Delta I_m \cdot \Omega_m + I_m \cdot \Delta\Omega_m = 0. \tag{2}$$

Since there was no change in the moment of inertia of the core given larger mass density constructed by iron-nickel materials, $\Delta I_c = 0$. The rotation rate of the core changed through the frictional force acted by vertical cells in the outside magma fluid layer, *i.e.*, $\Delta\Omega_c \neq 0$. For the fluid layer, $\Delta I_m \neq 0$ and $\Delta\Omega_m \neq 0$, because there were different velocities and moving directions of the magma fluids. Thus, Equation (2) becomes,

$$I_c \cdot \Delta\Omega_c + \Delta I_m \cdot \Omega_m + I_m \cdot \Delta\Omega_m = 0. \tag{3}$$

The vertical and meridional mass transformations of the magma fluids could lead to changes in its moment of inertia. However, if assuming that the magma fluids were incompressible and no redistribution of spatial mass, thus $\Delta I_m = 0$ and

$$I_c \cdot \Delta\Omega_c + I_m \cdot \Delta\Omega_m = 0\,. \tag{4}$$

The change amplitude of the core's rotation rate is directly proportional to the geomagnetic intensity and polarity, so the term $\Delta\Omega_c$ could be measured indirectly. The change amplitude of the entire magma fluid's rotation rate can be expressed in terms of the change rate of the core rotation as follows,

$$\Delta\Omega_m = -\alpha_{cm} \cdot \Delta\Omega_c, \tag{5}$$

or

$$\frac{\mathrm{d}\Omega_m}{\mathrm{d}t} = -\alpha_{cm}\frac{\mathrm{d}\Omega_c}{\mathrm{d}t}\,. \tag{6}$$

Here, the coefficient $\alpha_{cm} = I_c / I_m$ is a ratio of the moment of inertia of the core to that of the magma fluid layer. According to previous estimation [46], this ratio for the Earth-atmosphere system is $\alpha_{EA} = I_E / I_A \approx 0.569 \times 10^6$.

The crustal formation should be the result of Earth long-term cooling since its geological evolution. The interval spell of the core-magma angular momentum exchange should have at least 0.1 - 0.2 billion years in the earlier period of the geological evolution. There were planetary scale vertical circulations (including meridional and zonal cells) existed within the magma fluid layer since the geological evolution. The angular momentum exchange is realized through those vertical circulations, which also cause the horizontal temperature gradient and the horizontal circulation of planetary scale magma fluids at the upper level. The anomalous motion of horizontal circulation at the upper magma fluids (or upper mantle currents) near the bottom of lithosphere (crusts) was a real force to drive continental split and plate drift. The ratio should be $\alpha_{cm} = I_c / I_m \approx 1\times 10^1 \sim 1\times 10^4$ depending on different periods for the system. In the early period of the Earth's geological evolution $\alpha_{cm} \approx 1\times 10^1$, indicating that the magma fluid layer was deep. In the present days $\alpha_{cm} \approx 1\times 10^4$ because the magma fluid layer (an outer molten core) became thin due to the thickening of the solid inner core and the solid rocky mantle. Recently, Yang and Song [47] found that there is differential rotation which is associated with the angular momentum exchange from the core and mantle to the surface. Due to observational limitation, they only revealed an approximately seven-decade oscillation. In the early period of geological evolution, the oscillation should have a larger amplitude and a longer time interval.

Equations (5) and (6) give a relationship of the varied rotation between the inner solid core and the magma fluid layer. Their variations were directly associated with the intensity and collective direction of vertical cells in the magma fluid layer. If we have a reference frame relative to the inner solid core, the vector equation of motion for the magma fluids can be written as,

$$\frac{\mathrm{d}\boldsymbol{V}}{\mathrm{d}t} = -\frac{1}{\rho}\nabla p - 2\boldsymbol{\Omega}_c \times \boldsymbol{V} + \boldsymbol{g} + \boldsymbol{\chi}_{cm}. \tag{7}$$

Here, the velocity $\boldsymbol{V} = u\boldsymbol{i} + v\boldsymbol{j} + w\boldsymbol{k}$ is a vector which can project to the three directions orthogonal to each other, the two letters ρ and p are respectively the density and pressure of the magma fluids, and the vector $\boldsymbol{g}$ is the gravitational force acting on a fluid mass. The term $\boldsymbol{\chi}_{cm} = \frac{\mathrm{d}\boldsymbol{\Omega}_m}{\mathrm{d}t} \times \boldsymbol{r} = -\alpha_{cm}\frac{\mathrm{d}\boldsymbol{\Omega}_c}{\mathrm{d}t}$ is the frictional force by the core-magma angular momentum exchange, where the vector $\boldsymbol{r}$ indicates a fluid mass to the Earth's center in the vertical direction.

Equation (7) can be written in local coordinates by considering only the large-scale horizontal motion,

$$\frac{\mathrm{d}u}{\mathrm{d}t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + f_\varphi v - \alpha_{cm}\frac{\mathrm{d}\Omega_c}{\mathrm{d}t} r\cos\varphi, \tag{8}$$

$$\frac{\mathrm{d}v}{\mathrm{d}t} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - f_\varphi u. \tag{9}$$

Here, u and v are respectively horizontal velocities of magma fluids along the x direction (from west to east) and the y direction (from south to north), the Coriolis' parameter writes as $f_\varphi = 2\Omega_c \sin\varphi$, φ is latitude. $\chi_{cm} = -\alpha_{cm} \frac{\mathrm{d}\Omega_c}{\mathrm{d}t} r\cos\varphi$ along x direction, indicating that if the rotation rate of the core is slowing down the magma fluids will obtain an eastward force to increase its eastward moving. The velocity of eastward moving reaches the maximum near the equatorial zone and reaches zero at the two poles.

In the early period of the Earth, the magma fluids were zonally well-distributed, so $-\frac{1}{\rho}\frac{\partial p}{\partial x} = 0$. For simplicity, we also let $-\frac{1}{\rho}\frac{\partial p}{\partial y} = 0$ at the planetary scale. Thus, we have,

$$\frac{\mathrm{d}u}{\mathrm{d}t} = f_\varphi v + Ar\cos\varphi, \tag{10}$$

$$\frac{\mathrm{d}v}{\mathrm{d}t} = -f_\varphi u. \tag{11}$$

Here, $A = -\alpha_{cm}\frac{\mathrm{d}\Omega_c}{\mathrm{d}t}$. Combining Equations (10) and (11), Equation (12) can be obtained as,

$$\frac{\mathrm{d}^2 v}{\mathrm{d}t^2} + \beta u + f_\varphi^2 v + A f_\varphi r\cos\varphi = 0. \tag{12}$$

Here $\beta = \frac{\partial f_\varphi}{\partial y}$ is called β effect due to the meridional variation (along y direction) of Coriolis' parameter. It causes meridional motion to form waves such as Rossby wave.

For planetary scale, Rossby wave can be viewed a perturbation and be neglected in Equation (12),

$$\frac{\mathrm{d}^2 v}{\mathrm{d}t^2} + f_\varphi^2 v + A f_\varphi r\cos\varphi = 0. \tag{13}$$

As an approximation, taking f_φ, A and r as constants at a fixed latitude, then the solutions are,

$$u = A\frac{r}{f_\varphi}\cos\varphi \sin f_\varphi t, \tag{14}$$

$$v = -A\frac{r}{f_\varphi}\cos\varphi\left(1 - \cos f_\varphi t\right). \tag{15}$$

We discuss the change in the motion direction of magma fluids when the rotation rate of the core changes. Keep in mind that $f_\varphi = 2\Omega_c \sin\varphi > 0$ in the Northern Hemisphere and $f_\varphi = 2\Omega_c \sin\varphi < 0$ in the Southern Hemisphere. When the core rotates faster from west to east, $A = -\alpha_{cm}\frac{\mathrm{d}\Omega_c}{\mathrm{d}t} < 0$. From Equations (14) and (15), the surface magma fluids had a westward motion component ($u < 0$ in both hemispheres) and subsequently formed a poleward motion component ($v > 0$ in the Northern Hemisphere and $v < 0$ in the Southern Hemisphere) due to the Earth rotation (Coriolis force). In other words, there were southeasterly (↖) flow in the Northern Hemisphere and northeasterly (↙) flow in the Southern Hemisphere. Similarly, when the core rotation becomes slower, $A = -\alpha_{cm} \frac{d\Omega_c}{dt} > 0$. Then the magma fluids had an eastward motion component ($u > 0$ in both hemispheres) and subsequently formed an equatorward motion component ($v < 0$ in the Northern Hemisphere and $v > 0$ in the Southern Hemisphere) affected by the Coriolis force, *i.e.*, northwesterly (↘) flow in the Northern Hemisphere and southwesterly (↗) flow in the Southern Hemisphere. The northwesterly (↘) magma fluids and the southwesterly (↗) magma fluids can form an orthogonal convergence or collision at the equator. This dynamical framework will be used to explain the continental drift in Section 3 and the uplifted Himalayans in Section 4.

3. Continental Formation and Plate Drift in the Early Earth Period

For the internal structure, the present Earth can be grossly divided into three main layers: an inner solid core with a radius of about 1220 km, an outer molten core from 1220 - 3480 km radius with a depth of 2260 km, and a solid rocky mantle layer from 3480 - 6370 km radius with a depth of 2890 km from the Earth surface [48] [49]. In the later stage of the astronomical evolution of the Earth, a large amount of heavy metal materials accumulated towards the center of the Earth and formed an inner solid core. The core is surrounded by the magma layer. At that time, the crust had not yet been cooled to form and the Earth was composed of the inner solid core and the outer magma layer. Even after the crust has thickened due to cooling, its thickness and volume are still negligible compared to the outer magma layer and the inner solid core. Magma fluids in the early days of the Earth were the most active parts of the planet. Thus, the mantle layer was the upper portion of the magma layer (mantle currents) during the early stage of the geological evolution. To compare with the present location of the mantle layer, the magma layer is named mantle currents.

Before the end of the Earth's astronomical evolution, the Earth and its inner solid core rotated faster [50]. Based on the dynamical analysis of Section 2, the initial faster rotation of the inner solid core means that the surface magma fluids with light silica materials converged to the two polar areas. The geopotential height of surface magma fluids is high at the north and south poles, while it is low in the equatorial zone. At the end of the Earth's astronomical evolution, light silica materials with faster rotation and higher surface geopotential height appeared in the two polar areas, which finally formed two continental polar crust caps when the magma surface was cooling. At about 4.54 billion years ago, two original supercontinents gradually formed in the mid-high latitudes while an original oceanic zone formed in the tropics. This is the origin of the oldest two cap supercontinents and one tropical oceanic zone. As a result, the crust was thin in the tropics and thickening with the increase of latitude toward the two poles. The water formed after the cooling of the Earth was concentrated in the tropical oceanic zone.

The uneven latitudinal variation of the crustal thickness and water distribution led to the planetary scale latitudinal-band and vertical-layer differences in the thermal distribution in the magma fluids. These thermal differences drove the vertical circulation and led to the core-magma angular momentum exchange. Starting from the geological evolution, the core-magma angular momentum exchange through the frictional torque at their boundary would lead to a decreasing in the rotation rate of the core. At that period, the crust has formed but it was thin, so the interaction between the inner solid core and the outer magma layer still played a dominant role through the vertical cells within the mantle currents. During the spell of the first decreasing of the core rotation, the upper mantle currents had a southeastward motion in the Northern Hemisphere and a northeastward motion in the Southern Hemisphere according to the dynamical framework discussed in Section 2. Therefore, the southwesterly and northwesterly mantle currents converge orthogonally at the geographic equator and form the surface equatorial convergence zone (ECZ) of mantle currents. The equatorward movement of mantle currents caused the continental crust cap at the high latitudes to split and moved southeastward in the Northern Hemisphere and moved northeastward in the Southern Hemisphere. The influence of the Earth rotation needs to be first considered on the mantle currents and then on the continental motions [51].

The two spherical cap areas of continental crust that were originally located at high latitudes in the two hemispheres are symmetrical and equal, but the continental plates split in the two hemispheres are unequal in size. The northern continental crust cap was split into the Eurasia continent, the North American continent and Greenland, as well as islands near each continent. The southern continental crust cap was divided into the African continent, the Australian continent, the South American continent, the Indian peninsula, the island of New Zealand, and the continent of Antarctica. The drift of these un-uniformly fragmented continental plates altered the overall angular momentum distribution of mantle currents, so that the geomagnetic pole had shifted from the geographic pole and the initial ECZ position of magma fluids has also shifted from the equator to that of intertropical convergence zone (ITCZ). The ITCZ serves as a border for the mantle currents and continents from the two hemispheres. No matter where ITCZ goes, the mantle currents on either side of it do not cross the ITCZ, and likewise the continental plates on both sides do not cross the ITCZ. Therefore, the mass of mantle currents and the area of continents are always equal on both sides of the ITCZ. By the way, there is a similar angular momentum exchange between the atmosphere and the solid Earth for the inter-annual time scale atmospheric motion [52] [53]. The atmospheric ITCZ also exists as a boundary between the Northern Hemisphere air flows and the Southern Hemisphere air flows. The masses of the tropospheric atmosphere are equal on either side of the atmospheric ITCZ on a climatological long-term scale but not on a sub-seasonal time scale [54].

There is a relative movement of various layers inside the Earth, so the Earth is a huge generator, and there is constantly an electromotive potential and geomagnetic distribution. The relative motion of mantle currents has both planetary scale and regional scale circulations. Therefore, the Earth's generator has planetary scale symmetric and regional scale asymmetric electromotive components. Also, the distribution of geomagnetism is not planetary scale symmetry, but a synthesis corresponding to multiple time-space scales. This is also an interesting issue concerned by geophysical scientists [55]. Thus, the magma motion relative to the Earth's core produces the Earth's magnetic field.

At the early stage of the geological evolution when southwesterly and northwesterly mantle currents in the Southern and Northern hemispheres converge at the equator along the ECZ, the north and south poles of geomagnetism coincided with the north and south poles of geography. After the ECZ shifted from the equator to the ITCZ position, the north and south poles of mantle currents also shifted relative to the geographic north and south poles. The present geomagnetic poles not only deviate from the north and south geographical poles, but also change over time [13]. Therefore, the geomagnetic pole is a geophysical indicator of the deviation of mantle currents relative to the overall motion of the Earth. The process of core-magma angular momentum exchange has a long-term scale of tens of millions of years or more, reflecting the direction reversal of geomagnetic poles. This directional reversal of geomagnetic poles is recorded on symmetrical geomagnetic bands on both sides of the mid-ocean ridge [56] [57]. By the way, during the early days of Moon's life, the Moon also had relative motion between the lunar core and the magma layer. Therefore, there was once a lunar magnetic field. As the Moon cooled, different layers solidified together. Thereafter no circle structure of layers can be found in the interior of the Moon and angular momentum exchange between layers (or the Moon's generator) stopped. The magma fluid layer on the Moon no longer exists, but residual magnetism is still present in the soil on the Moon [58].

4. Himalayans Lift Associated with Orthogonal Convergence of Mantle Currents

The Himalayas has a profound impact on the formation of oceans, climate change, animal extinctions, and the movement of lithospheric plates [26]. Mountain formation like the Himalayans needs humongous uplifting forces in the process. Where did these uplifting forces come from? A possible mechanism is the maximum shear stress created by an orthogonal convergence or collision between two continental plates driven by the upper mantle currents. As we have already known from Equations (14) and (15) that, during the period when the core loses angular momentum and mantle currents gain angular momentum, the upper mantle currents move southeastward (northeastward) toward the equator in the Northern (Southern) Hemisphere. These two hemispheric mantle currents, hence the two hemispheric continents above, converge or collide orthogonally at the ITCZ.

For simplicity, we examine a convergence or collision of two magma fluid parcels. In **Figure 1**, the red-dashed line represents the ITCZ, the yellow-dotted arrow indicates the movement of magma fluid parcel A moving southeastward from the Northern Hemisphere, and the white-dashed arrow indicates the movement of magma fluid parcel B travelling northeastward. The parcel A has a mass m_A and velocity v_A, and the parcel B has a mass m_B and velocity v_B. They both move on the surface of sphere with the Earth's radius r, so both the parcels of mass A and mass B have their centripetal force,

$$\boldsymbol{F}_A = \frac{m_A}{r} v_A^2 \boldsymbol{n}_A \tag{16}$$

$$\boldsymbol{F}_B = \frac{m_B}{r} v_B^2 \boldsymbol{n}_B \tag{17}$$

where $\boldsymbol{n}_A$ and $\boldsymbol{n}_B$ are directional unit vectors perpendicular to their stream-lines at the surface mantle currents. When two parcels reach to the point C, they converge or collide. The result of a collision between two forces is a shear stress, which can be expressed by the vector product of them,

Figure 1. Orthogonal convergence model of the Earth's surface mantle currents from the two hemispheres to the inter-tropical convergence zone (ITCZ, red-dashed line). Letter C or c is the orthogonal convergence point from two parcels (A and B, or a and b) of mantle currents. The yellow-dotted arrow indicates that the fluid parcel is moving southeast-ward, and the white-dashed arrow indicates that the fluid parcel is moving northeast-ward. The topographic base map simply shows that the fluid motion and the ITCZ are located on a sphere surface.

$$\boldsymbol{\tau}_H = \left(\frac{m_A}{r} v_A^2\right) \cdot \left(\frac{m_B}{r} v_B^2\right) \cdot \left(\boldsymbol{n}_A \times \boldsymbol{n}_B\right). \tag{18}$$

The shear stress $\boldsymbol{\tau}_H$ is perpendicular to the plane formed by $\boldsymbol{n}_A \times \boldsymbol{n}_B$. Since $\boldsymbol{n}_A$ and $\boldsymbol{n}_B$ are parallel to the Earth's surface, the shear stress $\boldsymbol{\tau}_H$ is perpendicular to the Earth's surface and pointing up and down in two directions. In other words, the two directions of shear stress are an uplifting force and another subducting force, respectively. The shear stress modulus is,

$$\tau_H = \left(\frac{m_A}{r} v_A^2\right) \cdot \left(\frac{m_B}{r} v_B^2\right) \sin\theta. \tag{19}$$

Here θ is the convergence or collision angle between two parcels. It reaches the maximum when their collision angle is equal to 90˚ (sin90˚ = 1), which is an orthogonal collision,

$$\tau_{HM} = \left(\frac{m_A}{r} v_A^2\right) \cdot \left(\frac{m_B}{r} v_B^2\right) = \left(m_A v_A^2\right) \cdot \left(m_B v_B^2\right) / r^2. \tag{20}$$

Otherwise, when their collision angle is larger or less than 90˚, the shear stress modulus will be reduced. In particular, the shear stress modulus becomes zero when their collision angle is 0˚ (tail-gating collision) or 180˚ (head-on collision), which means that uplifting force and subducting force vanish.

The total energies of tail-gating collision and head-on collision are respectively,

$$E_t = \frac{1}{2} m_A v_A^2 - \frac{1}{2} m_B v_B^2, \tag{21}$$

if $v_A > v_B$ for the tail-gating collision with $\theta = 0^\circ$ and,

$$E_h = \frac{1}{2} m_A v_A^2 + \frac{1}{2} m_B v_B^2, \tag{22}$$

for the head-on collision with $\theta = 180^\circ$.

If we take $m_A = m_B = m$, $v_A = v_B = v$, and the total energy of head-on collision is concentrated at an area r^2, a ratio σ between the total energy of head-on collision to the shear stress modulus is,

$$\sigma = \tau_{HM} / \left(E_h / r^2\right) = mv^2. \tag{23}$$

The shear stress modulus can be seen as energy density. Equation (23) shows that the energy density of orthogonal collision of two fluid parcels is mv^2 times as that of head-on collision.

The orthogonal convergence or collision of two magma parcels in **Figure 1** can be extended to that of two continental plates. We can imagine that since the mass (m) of a continent is vastly large, the collision-induced shear stress with two opposite directions (uplifting and subducting forces) supported by the surface mantle currents should be immense. The uplifting force and subducting force can persistently exert on a collision point to form a topographical ridge on one side and a topographical trench on the other side. This mechanism can well explain that a high mountain such as the Himalayans is formed in the north side of the ITCZ by the uplifting force and a low valley is formed in the south side of the ITCZ by the subducting force. The mountain range bulges into the Earth's lower atmosphere, while the mountain root invades the upper layers of the magma fluids. Therefore, this newly formed crust is thicker than the original crust. The digging of the crust into the mantle currents will impact the position of the magma fluid ITCZ, just like the atmospheric ITCZ position impacted by the topography on the Earth surface.

5. The Distribution of Mountains and Oceans on the Earth's Surface

Based on the results of Sections 3 - 4, we can better understand the distribution of mountains and oceans on the Earth surface. There are an initial state and a final state. The initial state of the Earth's surface is the relatively thick spherical crust caps at the two high latitudes and the relatively thin oceanic crust zone in the tropics caused by the faster rotation of the Earth in the early days (see Section 3). The final state is today's distribution of the Earth's landscape shown in Figure 2. As we have already discussed that these landscapes are the traces left by the continental drifts after the first several periods of reversal rotation directions caused by the core-magma angular momentum exchange. In Figure 2, the red dashed line is the ITCZ of surface mantle currents that span the entire equatorial vicinity. The three solid (two dashed) black arrows indicate that the continental eastern edges of Africa, South America, and North America (Australia

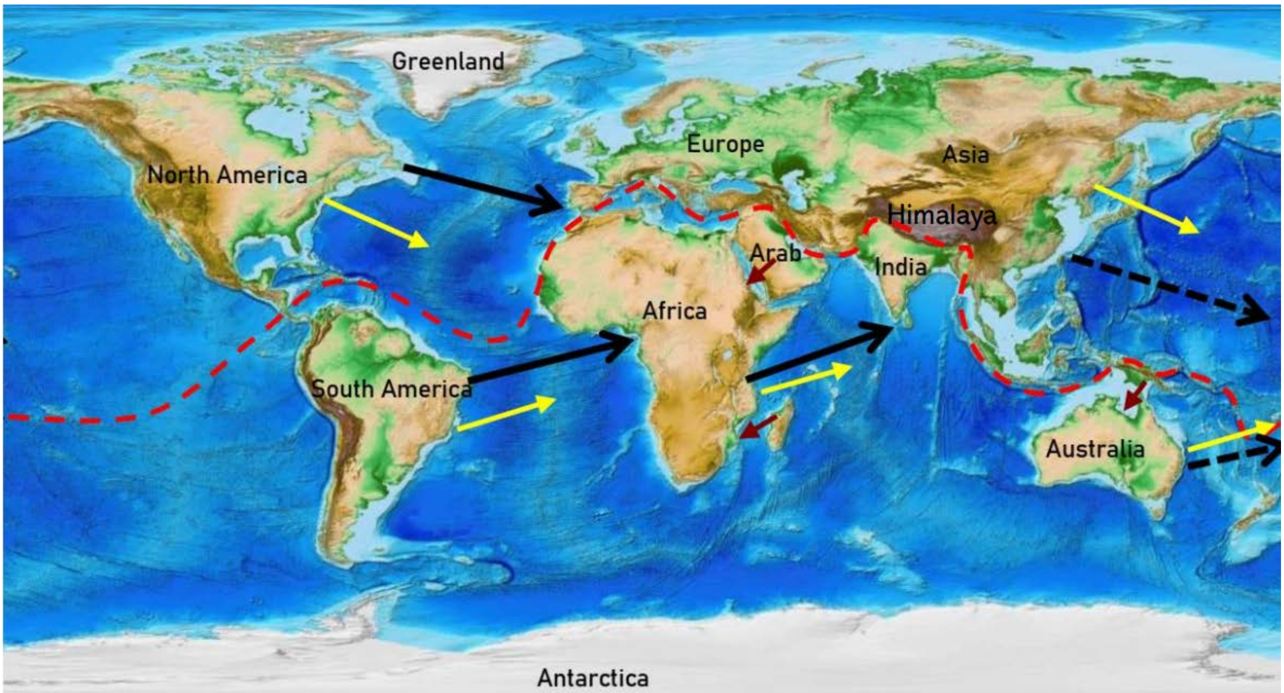

Figure 2. The present configuration of continents, mountains, islands, seamounts with mid-oceanic ridges and oceanic trenches in the world. The red-dashed line similarly as shown in Figure 1 indicates the ITCZ of the surface mantle currents after the Himalayas lifted during early periods of geological evolution.

and Eurasia) were once drift eastward and arrived in these places at the end of the first continental drift and formed a global supercontinent (except the Antarctica which stayed near the south pole). Five yellow arrows indicate that the eastern edge of five continents once reached the mid-oceanic ridges at the end of the second eastward drift. Three red arrows indicate the relative drift directions and locations of the New Guinea Island from the north part of Australia, the Madagascar Island from the southeast part of Africa, and the Arabian Peninsula from the northeast part of Africa. As mentioned already in **Figure 1**, the ITCZ is a line that the mantle currents did not cross from one side to another during geological history. Thus, the continental areas on both sides of the ITCZ are equal, so are the oceanic areas.

When the core lost angular momentum and mantle currents gained angular momentum during the first period of geological evolution, the surface mantle currents on both sides of the ITCZ moved toward the equator and eastward, driving the division of the mid- and high-latitude continental caps in both hemispheres to form various plates of different size. These thicker continental plates drifted to the equatorward and eastward. They finally shattered the oceanic crust in the tropics. The Eurasia plate in the Northern Hemisphere drifted southeastward, and then the North American continental plate and the Greenland plate also drifted southeastward to the west side of the Eurasia plate. When they reached middle and low latitudes in the Northern Hemisphere, a united continent which is similarly called as the Laurasia had formed. In **Figure 2**, the black line arrows on the North Atlantic indicate that the North American continental plate drifted to the northwest side of the African continent, while the Greenland plate drifted to the western edge of Europe. In the south of the ITCZ, the Australian continent, the India Peninsula, the Arabia Peninsula, the African continent, and the South American continent drifted northeastward after splitting from the middle and high latitudes. The arrows of the black line in the South Atlantic and Southern Indian Oceans indicate where the drift of the South American continent and the African continent had reached. The divided continent of Antarctica, due to its higher latitude, was not able to drift for any distance, but remained near the South Pole. These continents and islands from the south of ITCZ drifted northeastward to mid-to-low latitudes, forming a united continent, which can be similarly called as the Gondwana.

The two united continents at each side of the ITCZ moved toward the equator and converged or collided with each other orthogonally with their leading edges. The leading edge of the northern continents extends westward from the location of the present-day Himalaya to the Iranian Plateau, while the leading edge of the southern continents extends westward from the Indian Peninsula to the Arabian Peninsula. The maximum shear stress from the orthogonal collision provided the uplifting force for the formation of the Himalaya and the Iranian plateau. The uplifting force is enormous, which formed the uplift of the Himalayas and the Iranian plateau. The subducting force and horizontal motion momentum change can lead the front edge of a plate to subduct beneath the front edge of adjacent plate in opposite directions.

When the Himalayas bulged, there were only two continents in the world. One was the united supercontinent concentrated near the ITCZ, similar to Pangaea. Another continent was Antarctica. At that time, except for the two continents, the rest was oceans, named the Tethys Sea. The reversal direction of relative motion between the core and the mantle currents occurred many times, as indicated by the polarity change of the geomagnetic poles. As the core firstly accelerated since the geological evolution, mantle currents moved westward and poleward so that the united supercontinents (Pangaea) near the ITCZ cracked. Subsequently, the continents in the north of ITCZ drifted northwestward, while the continents in the south of ITCZ drifted southwestward. However, the central part has not obviously separated. For example, the Indian and Arabian Peninsulas collided orthogonally with the southern edge of Eurasia continent to form an uplifted thick crust on the ITCZ. The uplifted crust with mountain roots from the Himalayas and to the Iranian Plateau as well as the Indian and Arabian Peninsulas formed along the ITCZ so that they have never been separated since then. The southwestward drift of the African continent formed the Mediterranean Sea. The southwestward drift of the South American continent formed the South Atlantic. The northwestward drift of the North American continent and the Greenland formed the North Atlantic.

After the period of the formation of the global union supercontinent (Pangaea) and the continent of Antarctica, the oceanic crust was cooled. The southwestward drift of the South American continent and the northwestward drift of the North American continent were blocked by the cooled oceanic crust of the Pacific on their west coasts. The collision of the western edges of these two continental plates with the eastern edge of the Pacific crust uplifted the south-north oriented Andes and the Rocky Mountains.

When the mantle currents accelerated and moved eastward again, the eastward drift of the North and South American continents was blocked by the cooling and thickening Atlantic crust. Their eastward drift slowed down and finally their eastern edge stayed at the mid-ocean ridge of the Atlantic Ocean. The distance indicated by the yellow arrows in **Figure 2** is the range that the eastern edges of various continents reached during their eastward drifts.

During the return of the westward motion for the mantle currents, it drove the various continental plates at the low and mid-latitudes to drift westward, leaving the eastern edge of the continents behind. The mid-ocean ridge of the Atlantic Ocean and the mid-ocean ridge of the Indian Ocean are the traces left on the oceanic crust after the continents drifted westward.

In the nearly one billion years since the geological evolution, the core-magma angular momentum exchange caused multiple reverses of the Earth's magnetic field and multiple changes in the direction of mantle currents. The directional changes in the magma motion in the first 2 - 3 times led to significant drifts of continental plates. As the oceanic crust thickens, the drifts of continental plates driven by mantle currents become more difficult. Later, the traces left by the apparent drift of continents are shown by the red arrow in **Figure 2**. The southwestward drift of the African continent separated the Arabian Peninsula and the Madagascar Islands. The southwestward drift of the Australian continent left the New Guinea Island in the northeast side.

Figure 2 shows that the drift of global continents is directional. Throughout the geological evolution, the continental plates in the south of the ITCZ have generally drifted northeastward, while the continental plates in the north of the ITCZ have generally drifted southeastward. The islands in the south of the ITCZ are generally located on the northeastern side of each continent. The islands in the north of the ITCZ are mostly located on the southeastern sides of each continent. Since geological evolution, the two primordial supercontinents located in the two polar regions have shifted towards the ITCZ, forming the supercontinents of Laurasia, Gondwana and Pangaea, until modern land-sea distributions.

6. Conclusions

Our planet is a dynamic system that has undergone geological changes from its formation to evolution. As a living entity, it provides people with resources, yet unleashes countless disasters. To seek benefits and avoid harm, human beings must first understand the internal laws of change of the Earth and then use dynamic models to predict them. We have developed a theory of planetary-scale dynamics that describes the formation, splitting, and drifting of continents throughout Earth's early history. This theory encompasses the exchange of core-magma angular momentum and changes in the directionality of mantle currents that cause splitting and drifting of the Earth's crust. The purpose of this paper is to identify the theoretical process of this evolution and its remaining traces, in order to draw the following conclusions.

6.1. The Earth System Composed of Inner Solid Core and Outer Magma Layer

Right after the Sun has formed, there is a large amount of material (planetesimals or planetary embryos) rotating in a plane outside the Sun. The Earth was born in one of the larger planetary embryos [59]. Lots of small embryos and other interstellar materials converged into larger planetary embryo by their orbits [60]. Initially, the Earth was a cooler solid embryo, like Mars's moons that did not develop. Later, a lot of asteroid embryos hit (converged to) the Earth's embryo, kinetic energy was converted into heat energy, and the temperature gradually increased while the volume and mass also increased. Finally, its surface is molten with a globular shape [46]. The early internal structure of the Earth is an inner solid core and an outer magma layer under high-pressure and high-temperature equilibration. At that time, its rotation speed reaches the maximum magnitude, which is the end of Earth's astronomical evolution and the beginning of geological evolution. Under the influence of high rotation speed and gravitational differentiation, lighter materials were concentrated on the surface of the Earth's north and south poles.

6.2. Drivers of Original Crust Cap Split and Continental Drift

As the Earth started cooling, the two polar crust caps were formed and thicker than the equatorial belt crust. At that time the magmatic fluid layer has been covered by thin, less dense crust. Thus, the Earth system consisted of inner solid core, magma layer, and outer crust. The magma layer reached a depth of 5000 km, and the temperature difference between the equator and the polar regions and different sublayers formed planetary scale magma circulations, resulting in the core-magma angular momentum exchange. When the core loses angular momentum and the magma layer gains angular momentum, we theoretically derive a set of solutions for the directional motion of upper mantle currents. The upper mantle currents in the Northern (Southern) Hemisphere move southeastward (northeastward). The planetary scale motion of upper mantle currents forms a magma fluid convergence zone at the Earth's rotating equator. The magma fluid mass and area on both sides of the ITCZ are symmetrical, as are the crust area and thickness of the two hemispheres. Because the crust is thin and light, its splitting and drifting are driven entirely by upper mantle currents. As a result, the relatively thick crust at the north and south poles broke up and drifted eastward and equatorward. Therefore, the driving force of global continental division and drift is the directional motion of upper mantle currents caused by the core-magma angular momentum exchange.

6.3. Shear Stress on the Uplift of the Himalayans

As the world's highest terrain, the Himalayans, its uplift requires huge local forcing. Once this question can be answered, the global distribution of mountains is easy to explain. During the first movement of upper mantle currents toward the equator and east, magma fluid parcels moving southeastward in the Northern Hemisphere converge or collide orthogonally with magma fluid parcels moving northeastward from the Southern Hemisphere. Orthogonal convergence or collision produces shear stress with two opposite directions vertically to the spheric surface, which is uplifting force and subducting force. As a result, the two hemisphere plates that drift to the ITCZ are uplifted and subducted respectively by the shear stress near the ITCZ. The uplifted topography is the Himalayans in the north side of the ITCZ while the subducted topography in the south is a valley nearby. While the Himalayans were uplifted, the split continents from mid-high-latitude areas drifted to mid-low latitudes and centered the Himalayans, except that the continent of Antarctica remained near the South Pole, forming the so-called combined supercontinent or Pangaea. Thus, the uplift of the Himalayans is caused by the shear stress of two-magma parcels and plates colliding orthogonally on the ITCZ.

6.4. Formations of the Mediterranean Sea and the Andes

When the core gains angular momentum and the magma layer loses angular momentum, the supercontinent (Pangaea) concentrated near the ITCZ begins to split. The Himalayans and its nearby continents lie on the ITCZ and are not drifted away. Other continents at low and middle latitudes, drift southwestward in the Southern Hemisphere, and drift northwestward in the Northern Hemisphere, forming two distinct topographic distribution characteristics. One is the formation of the Mediterranean Sea near the ITCZ. Second, the westward drift of the North and South American continents collided with the oceanic crust cooled over the place of the Pacific Ocean, forming the Andes and the Rocky Mountains. This process is called the returned drift of continental plates, but they cannot return to their original places because new oceanic crusts have formed by the cooling.

6.5. Formation of Mid-Ocean Ridges and Directionality of Continental Drift

Mid-ocean ridges retain important information left by continental drift. The most notable one is the Mid-Atlantic Ocean Ridge. In the theoretical derivation of this paper, the Mid-Atlantic Ocean Ridge is the arrived location when the North and South American continents drift eastward again. When the core and the magma once again exchange angular momentum and the North and South American continental belts drift back westward again, their eastern edge leaves a north-south ocean mountain range on the middle Atlantic Ocean. People refer to such mid-ocean mountains as the Mid-Atlantic Ocean Ridge. Relative drift of other continents has also left mountain traces on the oceanic crust. The continental plates drift back and forth many times relative to the oceanic crust. Each time it left traces on the oceanic crust. As the oceanic crust cools and thickens, the distance of continental drift gradually shortens. The last apparent drift of continents showed that the Arabian Peninsula and the Madagascar Island separated the African continent, and the New Guinea Island separated the Australian continent. The last significant marks left by continental drift are those trenches in the oceans and rifts on the continents. Since geological evolution, the Earth has gradually cooled, and its rotation rate has gradually slowed down with weakening fluctuations. As the crust thickens to the mantle layer, the thickness of the magma fluid layer decreases. Although planetary scale continental drift no longer occurs, local earthquakes and volcanic activity still occur. Remained global phenomenon is that the islands in the Southern Hemisphere are located on the east and northeast sides of their continents, and the islands in the Northern Hemisphere are located on the east and southeast sides of their continents. This is the directionality of continental drift [61].

7. Discussion

The traces left behind by the Earth's evolution are the result of dynamic interactions between multiple temporal-spatial scales and multiple layers. In the early stage of geological evolution, magma fluid layer was hundreds of kilometers thick, and there are vertical circulation and horizontal vortex movements at planetary, basin and local scales. They not only alter the exchange of angular momentum between the core and the magma fluid layer, but also lead to crustal movement and earthquakes and volcanic activity. As the crust cools and thickens to present mantle, planetary scale movement (continental drift) is no longer possible. However, convective motion at the local scale in any layer will still exist. In the early stage of geological evolution, the set of hydrodynamic equations that describe and simulate the motion of the Earth's atmosphere and ocean can also be applied to mantle currents. Planetary scale and long-term scale motion of magma fluids is the background to local convective motion, and even the energy source for convective motion. Therefore, the nesting and combination of the mantle convective pattern with the background model will be the way to improve the early warning and forecasting of geological disasters in the future. When it comes to the description of different space-time scale phenomena, we need to use different dynamical ideas and methods.

Theoretical research, numerical models and data analysis are the basic methods used in the description of the Earth's crust and the prediction of geological disasters. In the analysis of geological historical data, the traces left by the Earth's evolution can be summarized, and some laws of geological activities can even be obtained statistically. Numerical models are an effective way to quantitatively describe geological activities and predict geological hazards in the future. The basis of mathematical models comes from theoretical research. Theoretical study does not give specific quantitative results, but it will give the right direction or mechanism to develop other methods. For example, local convective models and other existing dynamic models are difficult to describe the traces left by crustal motion on planetary and long-term scales. It is foreseeable that numerical models should be the concretization (or refinement) of theoretical research. The theoretical research in this paper revealed the directionality of continental drift in geological evolution and the orthogonal collision effect on the Himalayas uplift through the shear stress interacted by two magma fluid parcels. The orthogonal collision of two-beam particles in high energy physics can generate extremely high energy density for the formation of a new physical state [62]. These basic results obtained by theoretical research should be described and reflected in numerical models.

Although this dynamical framework in its present format, given its very long-term scale, can only explain the historical aspect of the continental formation and plate drift as well as mountain and ocean formations, more developments are possible. Under the basic assumption that the real driving force for continental plate's movement is dependent on the motion of upper-mantle currents, we can merge this dynamical framework with other existing dynamical models focusing on a shorter time scale and local space scale like mantle convective models. By doing so, a more comprehensive dynamical framework might be developed and able to numerically simulate and even predict the Earth's plate movements for all temporal and spatial scales. Accurate predictions of earthquakes and volcano activities might not be a dream one day.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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