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A new insight into the driving mechanism for plate tectonics —the relationship between tectonic processes and the circumferential tensile forces associated with a rotating planet—

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Abstract

Mantle convection currents are the currently accepted driving force for plate tectonics that have ripped apart the continents and created oceans. Because of these actions, continental collisions and ocean closures have resulted. Our paper challenges the conventional concept and provides an alternate, mathematically justified drive mechanism. The pull-push motions of such convection currents in the upper mantle are here concluded to be too weak to be the driving mechanism.

Our proposal for such global scale forces concerns the effect of an offset centre of mass of the Earth that results in rotational wobbling. Kepler's laws of planetary motion demonstrate the rotational behavior of the Earth to be aligned with the Sun on the outward and inward motions of the elliptical orbit. The unbalanced rotation on a fixed gravitational axis results in circumferential stresses on the outer Earth's rim that is more than strong enough to pull the continental plates apart. The proposed unbalanced rotational stress force equation is shown to be sufficient to drive the cyclic breakup and reassembly of the continental plates, as well as the generation of new oceanic crust and subduction zones. Mantle convection currents are here demonstrated to have a passive rather than active role in the plate movements.

Keywords: Differential circumferential tensile force, Rotating Earth, Offset centre of mass, radius of eccentricity

Introduction

The theory of plate tectonics with the breakup and reformation of the Earth's crustal plates has been studied for over a century. Alfred Wegener first published the concept of continental drift in 1912 (Wegener, 1912). However, the driving force behind this phenomenon has proved difficult to demonstrate and defend mathematically. Holmes (1929) studied the internal structure and radioactivity of the Earth and proposed subcontinental (i.e. mantle) convection currents as a driving mechanism to drag the crustal plates. It remains difficult to find direct evidence of this effect. Geological evidence for the motion of the crustal plates accumulated through to the 1960s when seafloor spreading, and subduction zones were proved to support the theory of plate tectonics.

Hess (1962) postulated that subduction of the oceanic crust created a "slab pull" of the plate as the mantle convection current descended and cooled. This idea gained wide support and has been the most widely accepted drive mechanism for plate tectonics through into the 21st century. There are alternate theories that include mantle plumes and surges of mantle currents in a series of channels. Mantle plumes or "hotspots" do exist, but they appear to be of minor distribution and not capable of pushing huge crustal plates apart. The force of the mantle currents and slab pull must invoke a high friction coefficient for the movement of the lithospheric plates, which has yet to have evidence or mathematical justification.

In Wegener's original 1912 paper (Wegener, 1912), he proposed that tidal and centrifugal forces were possible plate motion drivers, which were later disregarded in favor of mantle convection currents. The later 20th century researchers suggested that the oceanic crust to be in synchronous motion with the movement of the continent.

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This raises the possibility of the Earth's rotation to be a factor. This alternate explanation includes the gravitational force of the Sun and the Moon, global deformation resulting from true polar wandering and wobbles in the Earth's rotation. A stumbling block to a resolution on the driving mechanism has been the development of a working mathematical model as to how such forces would work.

Investigation into the driving force for plate tectonics stimulated our lead author whilst observing flat-lying Phanerozoic basalts and deep marine sediments in the Andean Mountain chain near Potosi in Bolivia. The realization that forces had raised the western side of South America from below sea level up to 5000m above sea level was profound. Following an in-depth review of papers on plate tectonics it became clear that the major continental plates have been in motion from the break-up of Pangaea in the early Jurassic 200 million years ago to the present day. However, the accepted driving force of mantle convection currents did not appear sufficiently strong enough to initiate and maintain this motion. The rotation of the Earth, with its wobble was an alternative force that had to be pursued.

The Earth has a wobble in its rotation, as is indicated from the precessional movements of the tilted spin axis and the presence of Milankovitch Cycles (NASA [URL, 1]). These closely mimic that of an unbalanced rotating body.

The unbalanced rotation is a result of the Earth having an offset centre of mass (COM) with respect to the principal spin axis. This is based on Kepler's laws of planetary motion and the work carried out by Steiger and Bunton [URL] demonstrates that the daily readjustment of the daily rotation of the Earth is always aligned to the Sun on its motion towards aphelion and perihelion on its elliptical orbit. The gravitational pull between the Sun and the planets controls this action.

Equations were derived (and presented in this paper) using the Earth as an unbalanced rotating body with an offset COM. This was to quantify the magnitude of the circumferential tensile stresses developed in the Earth's rim as a function of the distance between the COM and the centre of rotation (the radius of eccentricity). The subject equations of the differential circumferential tensile forces (DCTF) relate to the cyclic break-up and reconstitution of the continental plates. Plus, the equations are also used to separate the forces of continental break-up from the forces initiating and sustaining subduction. This allows for the concept of momentum to be applied to a moving continental plate (CP), which will only stop at another converging boundary, thus initiating orogenic activity at the collision zone. Mantle convection currents are demonstrated to exist in passive mode with the development of mid-ocean ridges, mantle plumes and subduction zones.

Assessment of the Accepted Theory for Plate Tectonics Driving Mechanism

The long-accepted drive mechanism for plate tectonics movement is based on the Hess model (Hess, 1962), here summarized in Fig. 1. Subduction of the colder and denser oceanic crust downward into the mantle is interpreted to be the result of slab pull combining gravity effect and asthenosphere convection currents. In addition, the upwelling of magma and the associated volcanic activity at mid-ocean ridges is credited with imparting the force of ocean floor spreading. Despite the high degree of acceptance of mantle convection currents as the driving mechanism for plate tectonics, they do not appear to have a mechanically proven explanation and a mathematically justified theory of how this process works. In our publication research, we have observed that there are a significant number of parameter assumptions that must be made that generate a wide variety of possibilities of outcome.

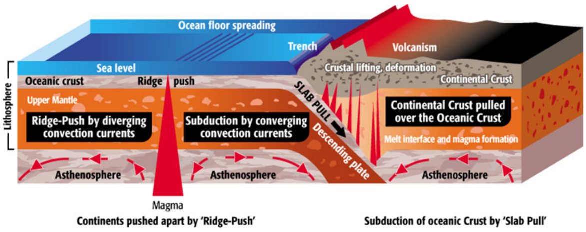


Fig. 1. The Hess convection current 'Slab Pull' – 'Ridge Push' model

Dewey (1976), Dewey and Bird (1970), Van Andel (1997) and Davies (2001) discuss the geometrical aspects of tectonic movement using Euler's Theorem, which states that the displacement of a plate over a spherical surface from one position to another can be regarded as a simple rotation about a suitable axis through the centre of the sphere. This implies that, in the case of the South American plate, the angular velocity will vary along its length. It is extremely difficult to understand how a convection current will match this rotational equatorial belt to the much smaller diameter polar latitudes. If the west-east convection currents were or are localised along a south-north axis within the upper mantle then, taken in isolation, a case for the movement of the South American plate may be made. The African plate appears to have been predominantly stable from the Triassic onwards, moving eastwards away from the Americas. However, it has also been pushing towards the north to north-east in closing the Mediterranean Sea over a long period of the Mesozoic and Cenozoic to the present day. Theoretically, convection currents could have moved the present Indian plate in a north-north-east direction into the Eurasian plate. This implies that the opposing convection currents must have been, and still are, stable over the 145 Ma period since the end of the Jurassic.

A further problem arises in consideration of how the convection based 'slab–pull' forces, which moved the components of Pangea northward from their original position in the Permian, changed direction in the Jurassic to cause the break-up of Pangea mainly in east and west directions contemporaneous with the simultaneously north and north-eastward clockwise rotation of the Indian and Australian plates. Nor can the existing current convection hypothesis reconcile the variation in the velocity of the different plates as illustrated by Park (1988) and Hamblin (1989). Overall, it is difficult to reconcile the movements of the various continental plates from their positions as part of Pangea over 275 Ma ago to their present positions, with the clearly omnidirectional convection current flow patterns.

The forces involved in pushing up the Andean Mountain chain to over 5,000m above sea level have been, and still are, continuously sustained in one direction. The direction of the forces will be perpendicular to the alignment of the mountain chain. The collision is between continental and oceanic crust, where the uplift of the Andes is currently attributed to the subduction of Nazca oceanic lithosphere by the 'slab pull' mechanism (Heirtzler & Bryan, 1976). In contrast, the continuing uplift of the Himalayas (to over 8,000m above sea level) along an east-west axis is attributed to the collision between two continental blocks. It is interesting to note that the subduction forces that are credited with moving India into central Asia are also credited with the continuing formation of the Himalayas. The continuously compressive and possibly isostatic forces now associated with the formation of the Himalayas appear to be far more complex than it would be if an obvious subduction zone were present at the India-Asia interface. Van Andel (1997) and Davies (2001) both discuss this matter in some detail and indicate that the major significant similarity between the different orogenic processes (Andean, Himalayan, and Alpine) is the sustained manner of the unidirectional movements and the forces involved. In contrast, we propose that the concept of momentum is used to explain the north-east movement of the Indian Plate and its collision with Eurasia.

Considerations of the Rotational Behavior of the Earth

The rotational behavior of the Earth and its possible impact on plate tectonics have been assessed by using mathematical modelling. The forces associated with the continuous unidirectional northward movement of Pangea from the Permian to the Jurassic would have had to have been constant over a long-time span. Only in this way could the westward movement of the Americas and the north-east movement of India and Australian have progressed from the Jurassic through to the present day.

Despite the apparent paucity of published research work on the influence of the rotation of the Earth on tectonic activity, there have been notable contributions on the rotational behavior of the planet. Waller and Holme (1996) considered the rotating Earth as a non-homogeneous shell that comprises an inner mantle which in turn surrounds a molten outer core, and a solid inner core. They further considered the core as being subject to dynamic heated convection currents as well as having a different rotational velocity to the upper layers. Sager & Koppers (2000) describe the movement of the Earth's spin-axis from as far back as the late Cretaceous. The movement of the Earth's spin-axis referred to by the authors as an 'apparent polar wander path' (APWP), is of the order of 3° to 10° per million years. Sager and Koppers (2000), Kearney and Vine (1990) as well as Courtillot and Besse (1987) suggested that this phenomenon might be the result of changes of inertia in the Earth's spin axis caused by the redistribution of mass in the mantle. Our literature survey did not uncover viable agreed explanations regarding the origin of the variable tilt angle of the Earth's axis (22.1°–24.5°) as well as the reasons for the Milankovitch (1952) precession movement cycles (NASA [URL,1]).

The most notable observations defined by Milankovitch cycles are:

a) The variation in the eccentricity of the Earth's orbit (over 100,000 years)
b) Oscillations in its degree of axial tilt between 22.1° and 24.5° (over 41,000 years) and
c) The precession ('wobble') of its axis as it changes from pointing towards Polaris (the North Star) to Vega then back to Polaris (over 23,000 years).

Taken together with the Chandler and other minor cyclical 'wobbles' the rotating Earth displays very similar characteristics to the mechanical behavior of a rotating shaft with an unbalanced load (Bishop, 1963, Lindley & Bishop, 1963). The 'Chandler Wobble' (3–15 metres at the North

Pole) which is superimposed on the other wobbling motions and has a rotation period of 433 days. The wobble is not unlike that of a spinning toy top. The simplified diagrams (Fig. 2a, b) illustrate a typical curve generated by a tilted unbalanced rotor wearing a round hole into an oval one in the supporting bearings. An everyday example is the balancing of a rotor from the measurements taken by displacement transducers to ensure vibration-free running (Fig. 2c). There are International Standards such as ISO 1940-1:2003 Mechanical Vibration, relating to the equations and methods adopted to dynamically balance rotating machinery such as flywheels, ship's propellers, and motor armatures etc. These equations are also well documented in almost every textbook on applied mechanics (Lindley & Bishop, 1963, Ryder, 1983).

In trying to determine a possible source or cause responsible for the Earth behaving like an unbalanced rotating body, some principal features of global tectonic activity were considered. As the ratio of the mass of the crust to the total mass of the Earth is low, the crust's surface position will have a negligible impact on the Earth's moment of inertia. We therefore tried to determine the Centre of Mass (COM) of the Earth and use that value to estimate the 'differential circumferential stress forces' (DCSF) created in the Earth's lithosphere.

The simple isostatic based equations to determine the COM taking into the account the average elevation of the African plate and depth of the Pacific basin do not yield a viable answer. Consideration of the Geoid with its asymmetrical distribution of mass nodes invalidates this approach. However, consideration of the spread of continental plates (CP) from the break-up of Pangea in the early Jurassic (200 Ma ago) to their present-day positions shows plate detachments on both western and eastern sides of the supercontinent. On the western side, the South American plate's westward movement opened the Atlantic Ocean at the expense of the Pacific Ocean (then known as the Panthalassa Ocean) reducing in size. On the eastern side the Indo-Australian plate broke away as a combined plate opening the Indian Ocean before splitting into two separate plates, the Indian plate moving north-east and the Australian plate moving eastwards below the equator into the Pacific basin. Simultaneously Laurasia at the northern end of Pangea split into Eurasia moving eastwards albeit very slowly and what is today North America breaking away westwards. The most significant point is that all the plates moved and are still moving continuously and unidirectionally towards the Pacific Basin. At present a large remnant of Gondwanaland namely the African plate is splitting apart along the north-south aligned Rift Valley and in doing so will open a new ocean, effectively an extension of the Red Sea. The eastward movements of the Japanese and Philippine islands away from Asia, which became detached in the Miocene period following the Indian / Eurasian plate collision needs to be considered in the same context. This scenario shows all the characteristics of an unbalanced rotating rigid body in which the heavier African plate side or hemisphere is in tension and the lighter Pacific Basin side (Ring of Fire) or hemisphere is in compression. It is this scenario that gave rise to the necessity of calculating the hoop stress levels of a rotating rigid body. For the purposes of calculating the induced stress levels in the outer rim, a 1 km offset was chosen as the position of the COM from the rotational axis of the Earth, located just east of the Prime Meridian on the African plate side of the Earth.

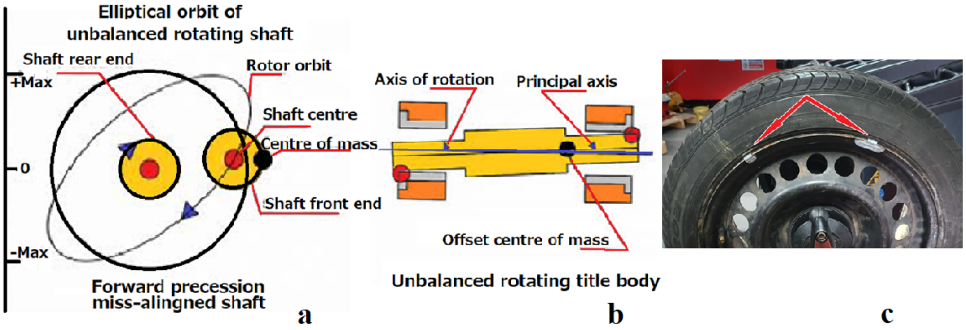


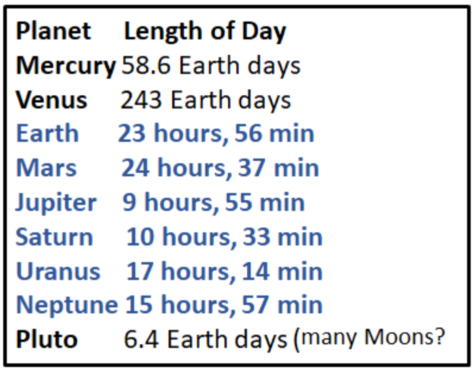
Fig. 2. Unbalanced rotating shaft model and the similarity to the circular to elliptical motion of the Earth's Milankovitch Cycles **a:** A similarity to the Milankovitch precession cycles in depicting the elliptical movement of an unbalanced rotating shaft whose COM is offset from the centre of rotation. **b:** The damaging effect on journal bearings supporting an unbalanced tilted shaft rotating around its mass centre rather than the intended geometrical centre. **c:** Balancing weights to avoid vibration.

Tensile Circumferential Stresses Modelling in an Unbalanced Rotating Earth

The rejection of, and the lack of research work into, this line of enquiry opposes Kepler's Laws of Planetary Motion (NASA [URL, 2]) which clearly demonstrate that the Sun controls both the orbital and rotational velocities of the Earth particularly for when the planets move in elliptical orbits. Kepler's Second Law describes the variable gravitational pull of the Sun on the Earth as it moves through a complete elliptical orbit by the cyclical speeding up and slowing down of the orbital velocity as the planets move towards and away from perihelion. Planetary movements are thus shown to be directly controlled by the mutual gravitational pull between the planets and the Sun and as such they cannot be considered as freely rotating bodies. This situation is clearly augmented by the motions as set out by Steiger & Bunton [URL]. This work clearly demonstrates that the Earth, in describing an elliptical orbit, must rotate 360 degrees on its axis plus a small angle (equivalent to the difference between sundial time and standard clock time of plus 7.7 minutes) between October and April as it moves closer to the Sun and decrease by the same amount between April and October (minus 7.7 minutes) as it moves further from the Sun. This ensures that the Sun returns to be directly overhead a selected spot on the Earth one complete orbit later and to remain in the correct position in relation to the stars. The difference of 7.7 minutes equates to approx. 1 degree of rotation per day during those periods.

It is essential that an offset torque moment be applied to rotate a planetary body. Furthermore, for a planet to be rotated about its principal axis of rotation by the mutual gravitational pull between the Sun and the planet, a 'handle' must be available on both the Sun and the planet to pull on. This concept and requirement also bring with it the exciting and unexpected conclusion that the COMs must be 'off centre' in order that the gravitational pull of the Sun, acting on the offset COM, will in fact provide a torque moment to effect rotation, and in doing so, the tilted principal N-S axis of rotation of an unbalanced rotating planet is established. This paper postulates that the offset COM was created when the Sun captured the accreted mass that would become planet Earth at the development stage of the Solar System. This approach has been extrapolated to the other planets and may well explain why all the planets in the Solar System are tilted in the same direction (except Venus which is inverted) and rotate with the same hand and in some cases with a similar daily rotation period (Table 1). Kepler's laws and the creation of an offset COM thus gives complete credibility to the mathematical modelling of the Earth as an unbalanced rotating body. At present 'wobbles' on other planets have not yet been observed except for a Chandler type 'wobble' on Mars **(**Konopliv et al., 2020**)**. The placement of the COM offset from the rotational axis of the Earth creates differential circumferential tensile forces (DCTF) in the Earth's rim.

Table 1 Length of day of planets



Planet	Length of Day
Mercury	58.6 Earth days
Venus	243 Earth days
Earth	23 hours, 56 min
Mars	24 hours, 37 min
Jupiter	9 hours, 55 min
Saturn	10 hours, 33 min
Uranus	17 hours, 14 min
Neptune	15 hours, 57 min
Pluto	6.4 Earth days (many Moons?

We propose that the offset COM and the anticlockwise rotational angular velocity were created by the gravitational pull of the Sun as it acted upon the large accretionary bodies which became the planets. It is the same offset COM that causes the rotational movements of the tilted Earth to mimic that of an unbalanced rotating body. The unbalance arises from the asymmetrical weight distribution within the rotating body. This in turn causes the differential circumferential tensile forces (DCTF) on the heavier side to be greater than those on the lighter side. In the case of the Earth, the crumpled Pacific Basin with its Ring of Fire have all the appearances of being in compression while the almost diametrically opposed African plate which is splitting at the East African Rift Valley appears to be in tension (Fig. 3).

Model 1: Rigid Body Dynamics

To aid the understanding of the dynamic effects of the planet Earth having an offset COM, two different models are considered to determine the principal forces associated with an unbalanced rotating body (Walker, 1981). The simplest model is to consider the Earth as an eccentrically rotating solid rigid body such as unbalanced flywheel in which the centre of rotation (COR) will be purposely offset from the centre of mass (COM) as shown in Figs. 4b and 5. The Radius of Eccentricity (**E**) is depicted as **δr**. Although this model diagram accounts for the compressive and tensile stresses developed in the outer rim, it does not describe the circumferential forces which are considered

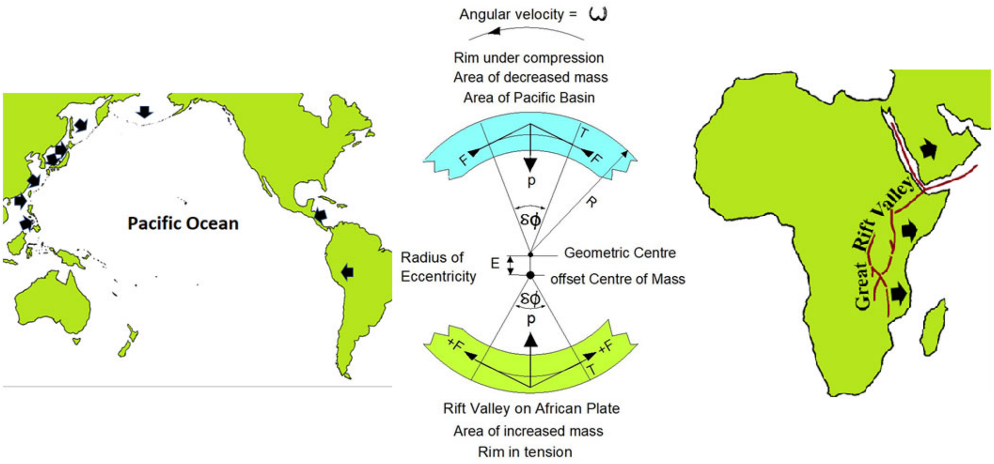


Fig. 3 Example of crustal compression and crustal tension

linked to the tectonic forces resulting in plate movement. For reference Fig. 4a demonstrates a balanced rotating body with COM at the COR. The mathematical analysis is included in Appendix 1.

This rigid body approach (Walker, 1981), (Figs. 4b and 5—see Appendices 1 and 2), while clearly demonstrating the differential circumferential tensile stress (DCTS) owing to eccentricity, is not considered as the model for tectonic movement. The DCTS effect is illustrated in Fig 3 which shows the heavier hemisphere in tension as noted by the splitting of the African Plate at the Rift Valley. Similarly, the topography of the Pacific Basin (Ring of Fire) on the lighter side of the hemisphere (at approx. 180° on the opposite side of the Earth to Africa) has all the characteristics of being in compression. In contradiction our model for tectonic movement is based on having relative movement between the outer rim or crust and the main body or mantle. Both models serve the very useful function of demonstrating the visual effects due to the mass imbalance of the rotating Earth. For small continuous movements

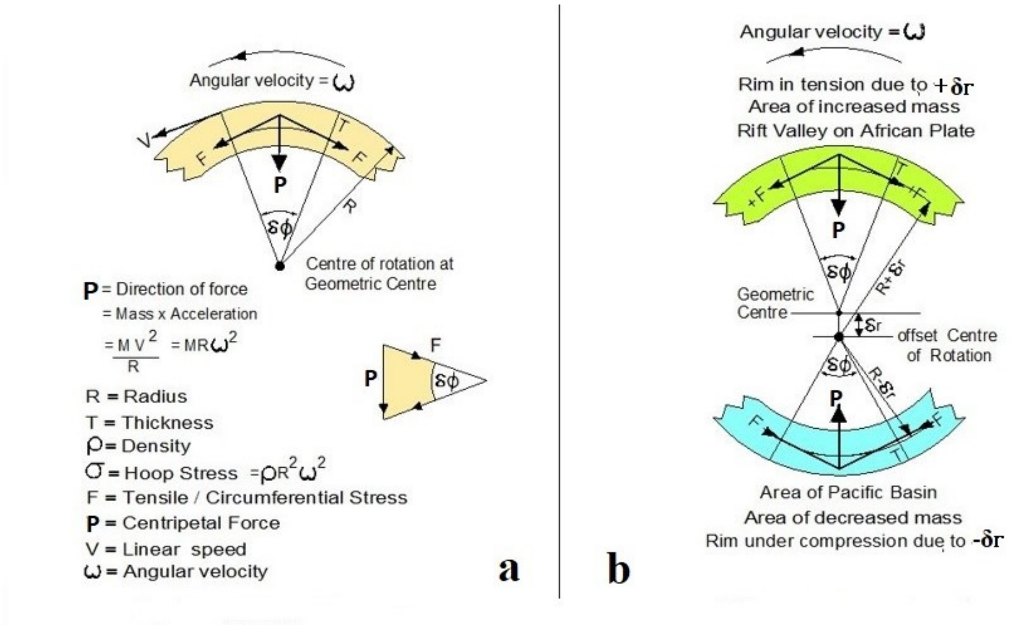


Fig. 4 Examples of tensile stress for a balanced rotating planetary body and a rigid planetary body
a: Centripetal force diagram. Tensile force in outer rim. **b**: Differential circumferential tensile stress diagram.

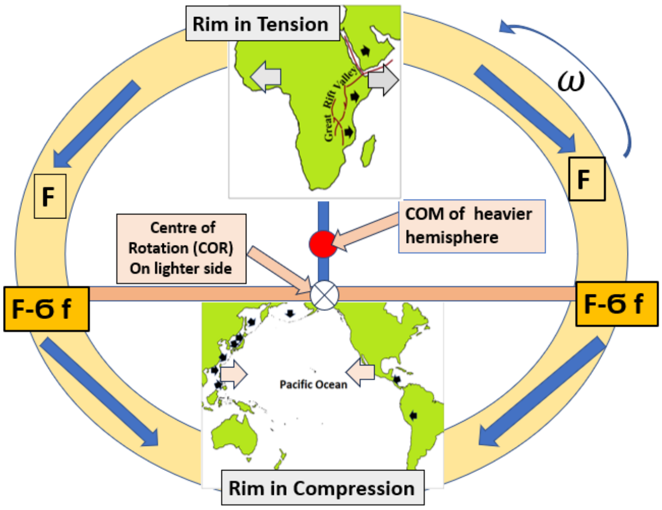


Fig. 5 Diagram of the Earth's differential circumferential forces for an unbalanced rotating body Diagram showing how the magnitude (F) of the circumferential forces subtended to the outer rim is related to the 1) E = Offset Centre of Rotation = 1 km & 2) (ω) the Earth's rotational velocity

(<0.25 km) of the COM, both models yield the same results. Model 1 describes the flywheel effect in which the centre of rotation (COR) is deliberately offset from a symmetrical centreline or position to ensure a heavier side.

Model 2: DCTS and Tectonic Plate Movement—Outer Layers able to Slide

For the purposes of this paper, the COM is offset from the symmetrical axis of rotation. In this model the area of maximum stress will be in the direction of the heavier side. This allows the mathematical analysis to be based on the concept of the outer rim (lithosphere) being allowed to slide relative to the main rotating body (Fig. 6).

To determine the forces postulated as being responsible for tectonic movement, the model used is one in which the lithosphere can slide relative to the solid body at the lithosphere-asthenosphere boundary. By way of illustration Fig. 6 Model A shows that if an unbalanced disc with an outer annular ring containing fluid is rotated about its principal axis, the liquid will move to the 'lighter' side. This action would also give a plausible explanation to account for the sea level in the Pacific Ocean being permanently higher than that of the Atlantic and Indian Oceans (Levitus et ai., 1977). This situation is noted by the difference in tidal heights either side of Panama. The mean of the tidal heights is also affected by weather patterns, salinity and possibly Coriolis forces. In Fig. 6, Model B shows the analogous situation in which the thin crust is made to slide from the 'heavier' side to the 'lighter' side. As the mass of the lithosphere is negligible when compared to that of the

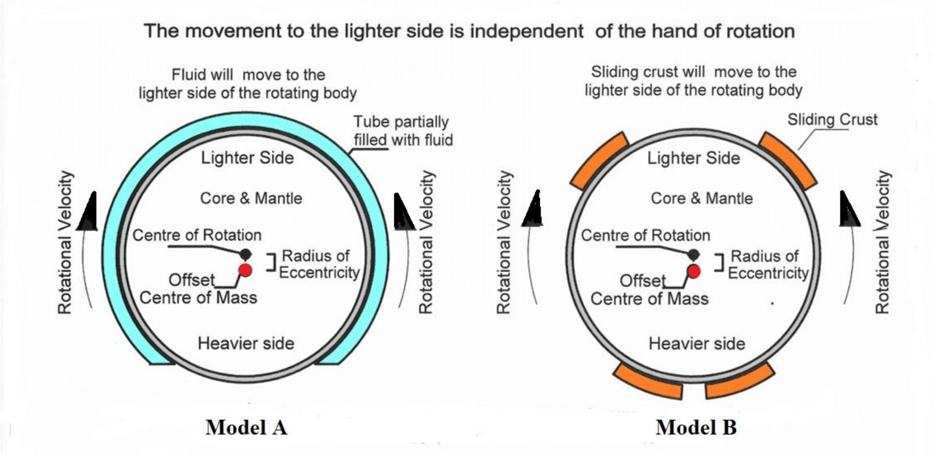


Fig. 6 Models used for calculating differential circumferential stress forces

whole planet, its distribution will have zero effect on both the moment of inertia and the position of the Earth's COM. Fig. 7a shows the vector diagram with the offset COM used to quantify the forces associated with a sliding lithosphere.

If we consider the lithosphere as being able to move relative to the asthenosphere, albeit it over a long geological time span, then a simple force diagram (Fig. 7a, b, c & d) can be constructed by making the following assumptions:

i. The lithosphere consists of a thin shell that can slide relative to the asthenosphere.
ii. The forces owing to eccentricity are superimposed on the stress caused by the general rotation and gravity.
iii. The stress that is of interest for the purposes of tectonic movement is the differential stress owing to this eccentricity.

By approaching the problem in terms of a thin lithospheric shell moving relative to the asthenosphere, it is possible to consider which increments of the tensile force are responsible for putting the Pacific Basin under compression and the African Plate under tension. The Rift Valley in Africa would be a case in point. The calculations to derive the expression of the circumferential stress (F) at the surface of the Earth are based on the consideration of the eccentrically induced loads on the thin crust. In calculating the effects of the circumferential forces (F) at the Earth's surface owing to the centre of mass (COM) being offset from the principal axis of rotation the term 'Radius of Eccentricity' was introduced to denote the size of this offset, i.e. the radius. In doing so the following relationship was derived:

Total circumferential force acting on the lithosphere =
$F = M R \omega^2 E \pi/4$—see Equation (2) below.

The magnitude of the derived circumferential stress (F) is thus dependent on the distance between the geometric centre and the centre of mass, i.e. (E) the 'radius of eccentricity'. In a limiting case, if the 'radius of eccentricity' is zero, the rotating body will be balanced, and the centripetal forces will be zero.

Consider a thin crustal shell cut across the Earth's diameter at the Mid-Atlantic Ridge (Fig. 7a, b, c & d). The force causing this half of the shell to part is the 'vertical' component of the centripetal forces generated by the eccentricity. This is similar in concept to that in thin shell circular vessels subjected to an internal pressure (Urry and Turner, 1982). Fig. 7c shows this concept of 'vertical force'. As the semi-circle is symmetrical there are two sides resisting the parting force. Thus, only one side needs to be considered for integration of the 'vertical' forces from 0 to π/2. Fig 7b shows the force and vector diagrams used to determine the magnitude of the circumferential stress in the

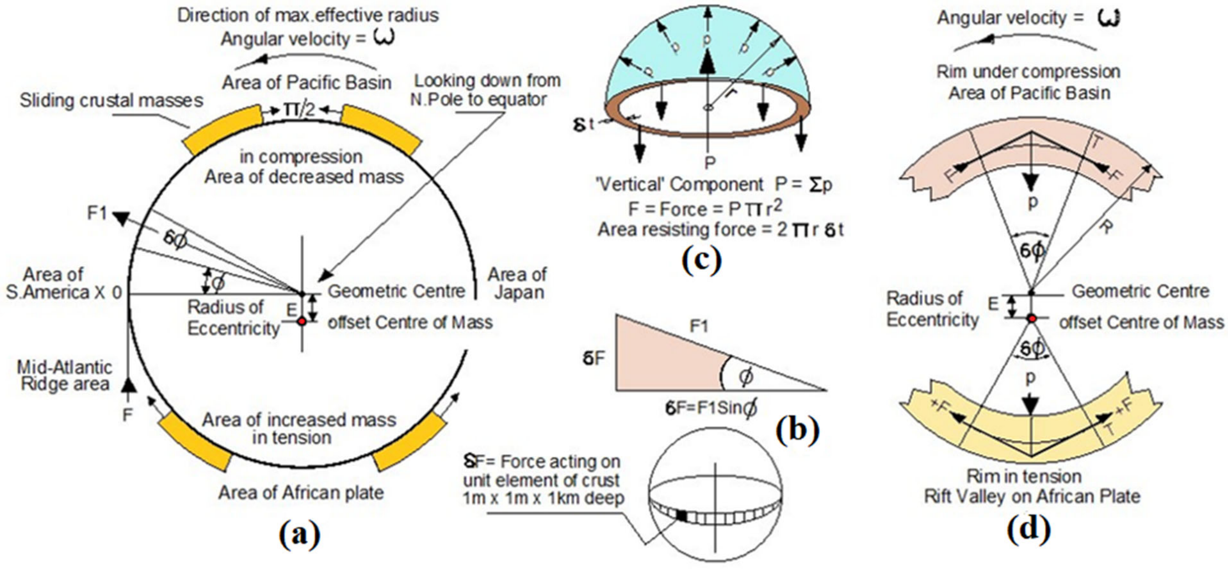


Fig. 7 Vector diagrams for the differential circumferential tensile forces
a: Principal forces superimposed across a section of the equator. **b**: Force diagram used to determine the total force (F) acting in the direction of maximum effective radius. **c**: Analogous derivation of the 'vertical' component in a thin shell sphere under pressure (P). **d**: Vector diagram showing the differential circumferential tensile forces.

direction of the maximum effective radius. For ease of understanding the force diagram is superimposed on the major geological features on the equatorial belt. Fig. 7d shows both versions of the vector drawing describing the mass imbalance due to the offset COM.

The mathematical analysis here is repeated in Appendix 3 to highlight the differences between Model 2 and Model 1.

Notations	**Values**
M = Mass per unit length of crust	2.8×10^6 kg
R = Radius of Earth	6.4×10^6 metres
E = Radius of eccentricity	1×10^3 metres
ω = Angular velocity	7.27×10^{-5} rad sec^{-1}
Ø = Angle (rad)	
δe = Effective eccentricity at angle Ø	
F = Total force at point X (N) (cf. Fig. 7a)	
F_1 = Radial force due to eccentricity at Ø	

Then from the ‘force vector diagram’ at surface at an angle Ø:

Vertical component of F_1 $\delta f = F_1 \sin Ø$

($= \delta F$ in Fig. 7b)

Effective eccentricity at angle Ø $\delta e = E \sin Ø$

and Mass of segment R δØ $= M R \delta Ø$

Thus, $F_1 = M R \delta Ø \omega^2 E \sin Ø$

$= M R \omega^2 E \sin Ø \delta Ø$

The vertical force component

$\delta f = F_1 \sin Ø$

$$= \mathbf{M R \omega^2 E \sin Ø \sin Ø \delta Ø}$$

$$= \mathbf{M R \omega^2 E \sin^2 Ø \delta Ø} \qquad \mathbf{(1)}$$

Thus, the total vertical force

$$\mathbf{F = \int_0^{\pi/2} M R \omega^2 E \sin^2 Ø \, \delta Ø}$$

$$= \mathbf{M R \omega^2 E \{(½Ø - ¼\sin 2Ø)^{\pi/2} - (½Ø - ¼\sin 2Ø)^0\}}$$

$$= \mathbf{M R \omega^2 E \{(\pi/4 - ¼0) - (½0 - ¼0)\}}$$

Total vertical force (F)

$$= \mathbf{M R \omega^2 E \pi/4} \qquad \mathbf{(2)}$$

The derivation of the equation of the total force at the maximum effective radius allows for the determination of the circumferential tensile stress on the crust. The approach given above considers the forces developed as a direct function of the radius of eccentricity.

If we consider, for Equation (2), the crust to be 1,000 metres thick with an average density of 2.8×10^3 kgm^{-3}, then for a column of crust of section 1 metre thick × 1 metre wide:

The mass per unit area of crust

$= 1{,}000 \times 1 \times 1 \times 2.8 \times 10^3 = 2.8 \times 10^6$ kg

The radius of the Earth (r)

= 6,400 km

The angular velocity of the Earth at the equator (ω)

$= 7.27 \times 10^{-5}$ rad sec^{-1}

The radius of eccentricity at the Core (E)

= 1 km

Hence substituting into Equation (2) we have

$$F = 2.8 \times 10^6 \times 6.4 \times 10^6 \times (7.27 \times 10^{-5})^2 \times 10^3 \times \pi/4$$

$$= 7.44 \times 10^7 \text{ N}$$

Since the magnitude of the circumferential stress is Force/Area

this becomes $7.44 \times 10^7 / 1 \times 10^3$:

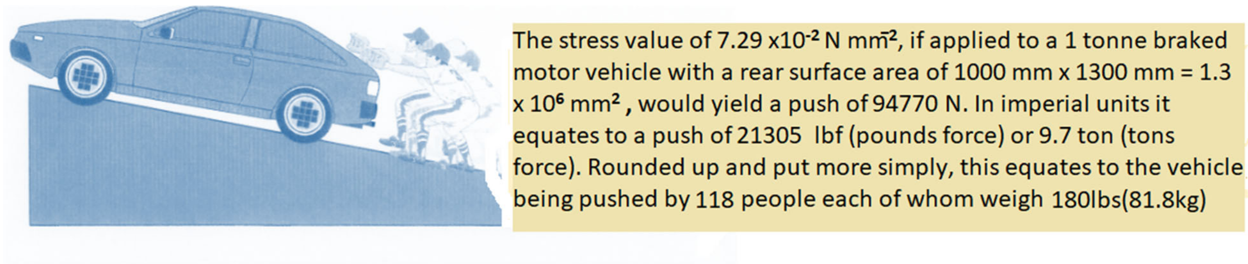
and hence

the circumferential tensile stress

$= 7.44 \times 10^{-2}$ Nm^{-2}, 0.744 Bar or c. 10.7 lbs in^{-2}

An Everyday Example Relating to the Magnitude of the Stress Forces

To better understand the magnitude of the calculated circumferential stress in the continental crust, it is helpful to relate the model to more familiar applications such as pushing a vehicle up a slope. This is illustrated in Fig. 8. The stress value of 7.29×10^{-2} Nmm^{-2}, if applied to a 1 tonne braked motor vehicle with a rear surface area of 1,000 mm × 1,300 mm = 1.3×10^6 mm^2, would yield a push force of 94,770 N. In Imperial units this equates to a push of 21,305 lbf (pounds force) or 9.5 tonf (tons force). Rounded up and put more simply, this equates to the vehicle being



The stress value of 7.29×10^{-2} N mm^{-2}, if applied to a 1 tonne braked motor vehicle with a rear surface area of 1000 mm x 1300 mm = 1.3 x 10^6 mm^2, would yield a push of 94770 N. In imperial units it equates to a push of 21305 lbf (pounds force) or 9.7 ton (tons force). Rounded up and put more simply, this equates to the vehicle being pushed by 118 people each of whom weigh 180lbs(81.8kg)

Fig. 8 An example of differential circumferential tensile forces to a modernday human example pushed by 118 people each of whom weighs 180 pounds (81.8 kg) (Fig. 8). If the altitude of the Andes is taken as 5 km and the distance between the Peru-Chile trench and the Cordillera–Real is taken as c.1,000 km, the incline is approx. 1:200 (0.5%). Therefore, the vehicle can be on a level surface for scaling purposes. Normally a 3-tonne hoist will easily pull the vehicle up a 1:3 incline onto a pick-up truck. It is also worth noting that an upward acting net force of 2.37×10^{-2} N/mm^2 (3.5 psig—i.e. gauge pressure relative to ambient atmospheric pressure) on a 60-metre wingspan of an aircraft is sufficient to keep a large 350 tonne aircraft flying. A puff of wind with dynamic pressure as low as 0.135×10^{-2} N/mm^2 (0.2 psig) acting on the large surface area of a ship's sail will cause the ship to move through water.

Generation of Momentum of a Moving Tectonic Plate

The development of equation describing the circumferential forces in the Earth's rim responsible for the break-up of a supercontinent, led to the consideration of the momentum of a moving CP after separation from the supercontinent (Maurer, 2001, 2022). Pangea is used as an example.

Perhaps the most important aspect in the breaking up of a supercontinent such as Pangea is that the plates will accelerate from zero velocity (Vo) to the present-day velocity (Vcp) of between 10–20 mm/year. In doing so, the continental plate (CP) has momentum imparted to it.

The gained Momentum = Mass × Velocity
Momentum of CP (P)
= Mass of CP (Mcp) × Velocity (Vcp − Vo)
= Mcp × Vcp

As the CP is moved away from the supercontinent (SC) by the circumferential forces, the weight of the overriding CP will push the oceanic lithosphere under it into the asthenosphere. In doing so, it will initiate the subduction process that will finally force the oceanic plate into the mantle. Under these circumstances, subduction is seen as a consequence of tectonic movements. The above hypothesis is against current thinking that considers that the net force (downward weight) – (viscous drag, friction, and buoyancy forces) associated with the descending slab is primarily responsible for tectonic movement as subduction under a CP.

The process of subduction is attributed to the difference in density between the heavier oceanic plate and lighter CP. The introduction of gained momentum **(p = Mcp × Vcp)** to the continental masses has resulted in a complete rethink of the cause and role of subduction and the presently accepted convection current forces. The detachment of the slab, either by break-off and with it the loss of the slab-pull force, rollback, or partial melting in the asthenosphere, have not hindered the movement of the CP. The gained momentum of the continental masses will keep them in motion. Whilst the velocity is low, the continental mass is extremely large. The overall momentum will make the slow but relentless movement of the CP unstoppable until it encounters another CP at what will become a convergent boundary. The creation of the Himalayas by India colliding with the Eurasian plate is the prime example of this action.

The logical and unexpected conclusion is that forces involved with the breakup of a supercontinent and the subsequent continental plate movement are independent of slab-pull and subduction resulting from density differences. The separation of subduction from tectonic plate movements is a major change in the study of plate tectonics. Subduction, and with it the forces associated with heated convection currents, are now seen as being closely associated with tectonic plate movements rather than being the driving force.

The following sections demonstrate that the forces are responsible for:

(i) the break-up of the supercontinent being a function of the differential circumferential stresses as distinct from
(ii) the forces causing subduction of the oceanic lithosphere under the continental lithosphere.

The break-up of the supercontinent makes itself manifest by the creation of oceans between the separated continental plates while the movement of the lighter CP over the oceanic plate initiates the subduction processes.

The role of momentum at convergent boundaries

At present the formation and deformation of accretionary prisms are generally attributed to 'subduction' and 'slab-pull'. An example is the subduction processes in the Nankai Trough which is interpreted as being formed by the simple northwestward movement of the Philippine Sea Plate due to mantle convection (e.g. Kimura et al. 2018). In contradiction, the opening of the Japan Sea and the formation of the Japan Arc in the Miocene have a complex plate movement ('double-door' mode) (Otofuji et al., 1985). Detailed paleomagnetic study of the Cretaceous to Miocene rocks demonstrates that the Japan Arc is composed of 2 arcs (Otofuji et al., 1997, Baba et al., 2007). In the Miocene

Japan Sea opening event, the northeastern part was separated from the Eurasian continent and drifted with counter-clockwise rotation, but the southwestern part was drifted with clockwise rotation (Otofuji et al., 1985, Baba et al., 2007). Despite its low velocity, the Japan Arc plate with its enormous mass has gained momentum supplied by the circumferential rim forces that will drive its movement into the Pacific Basin. These direct forces are very much greater than that supplied by thermal currents pulling a portion of the Pacific oceanic lithosphere under the Japan Arc plate. Furthermore, using this approach, viable explanations can be offered to explain the most notable CP to CP collision, that of the fast-moving Indian plate into the Eurasian plate. It is inconceivable that the compression and folding of the northern portion of the Greater Indian plate and the pushing up of the Himalayas were driven by deep-seated SW to NE thermal currents that would cut across the west to east currents driving the Australian plate. Similar consideration must also be given to the dynamic processes that allowed the uplift of accretionary wedges from below sea level to 5 km above sea level over a 7,000 km long South American plate moving across a spherical surface over a 145 Ma period. This scenario is easier to understand if the South American plate is moved by the permanent circumferential stress forces and its gained momentum would aid its movement over the Nazca plate (Fig. 9).

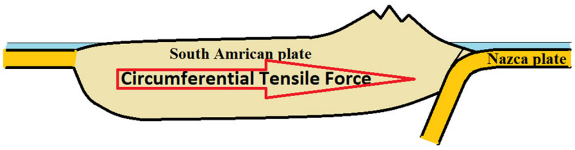


Fig. 9 A model for the tectonic movement of the South American Plate

Summary and Conclusions

This conceptual research work investigating the sustained unidirectional movements of tectonic plates away from the 'heavier' African plate towards the Pacific Basin since the break-up of Pangea in Jurassic time, has resulted in some unexpected findings and conclusions. These calculations are based on the observation that the tilt and variable processional movements of the Earth closely mimic the behavior of unbalanced rotating bodies where the centre of mass (COM) is not coincident with the axis of rotation.

This is against current thinking which states that the planets are freely rotating bodies about their centre of mass which coincides with the axis of rotation. However, Kepler's Laws of Planetary Motion clearly demonstrate the Sun's control over the planets' positions as well as their orbital and rotational velocities in an elliptical orbit. This can only be accomplished by a mutual gravitational pull between their offset COMs. As such the planets cannot be assumed to be freely rotating bodies with zero offset torque moments.

By considering the Earth as an unbalanced rotating body with an offset centre of a mass (COM), it has been possible to develop equations to quantify the magnitude of the circumferential tensile stresses developed in the Earth's rim as a function of the distance between the COM and the centre of rotation (Radius of Eccentricity). In doing so, this paper has principally demonstrated that the forces responsible for the break-up of a supercontinent and tectonic plate movements are separate and distinct from the forces initiating and propagating subduction.

Furthermore, the approach taken also allowed the following conclusions to be drawn:

1. For the planets to be rotated about a stable axis by the mutual gravitational pull of the Sun, the COMs of the planets and the Sun must be offset with respect to their axes of rotation to allow the gravitational pull to yield a 'torque' force. If the COM were positioned on the axis of rotation, the gravitational force would just 'pull' the planet rather than cause it to rotate. The planet Mercury with its very small tilt angle is an example. This is further reinforced by the fact that it is impossible to rotate a body about its dimensionless centreline without a driving force. The above-stated observation, which is applicable to all rotating bodies, may well explain why the planets rotate with the same hand (as seen from above the north pole) as does the Sun, and (excepting Mercury, Venus, and Uranus) have a similar tilt angle to the Earth. Also (excepting Mercury and Venus) they have a similar diurnal rotation period.
2. The above observation postulates that the establishment of the axis of rotation of each planet is a direct consequence of the COM being offset from that axis.
3. It is further postulated that the above-mentioned event occurred during the formation of the Solar System. This followed the collapse of a cloud of interstellar gas and dust (from which the Sun and planets formed), possibly due to a shockwave from a nearby exploding star. Nearly all the cloud condensed to form the Sun, and the planets and smaller bodies formed from the coalescing of the remaining material of the cloud that was orbiting the Sun.

4. For the Solar System to remain stable despite cyclic planet alignment or even long-term random perturbations, the system must have the means to re-adjust to the new conditions of gravitational pulls from the different planets and the Sun. This could entail slight changes in both the orbital paths and possibly the rotational behaviour of one or more planets. An offset detached COM (National Geographic [URL]) would allow these changes to be made by the altering of the axial tilt angles of the planets and thus their orbital journeys. Although this action would only be observed on water-laden planets, the rearrangement would in turn cause the break-up and reassembly of supercontinents to take different paths and have different configurations. Rodinia and Pangea are used as examples. However, the process of lithosphere regeneration will still be continuous (Fig. 10) as the distribution of CP's will be pushed by forces directly related to the Earth's rotational velocity. Random subduction cannot achieve this presently accepted c. 500 Myr cyclic activity as described by Mitchell et al., (2021).

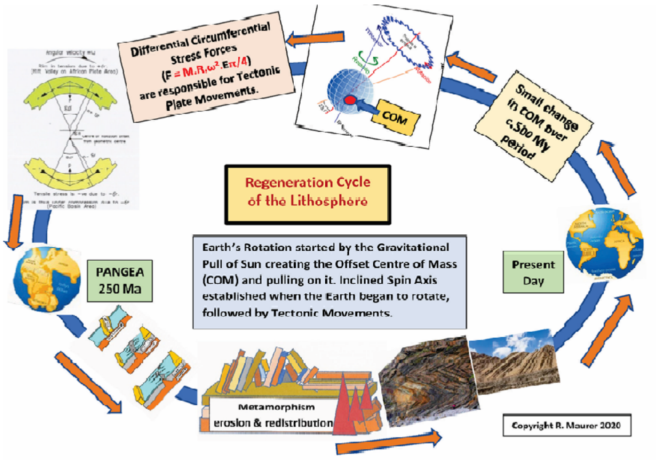


Fig. 10 The separation of the forces for Tectonic Movements from the forces driving subduction has allowed for the introduction of a different lithosphere recycling diagram to the Wilson Cycle regeneration cycle to be proposed

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Appendix 1:

Alternative analysis to calculate the differential circumferential tensile forces

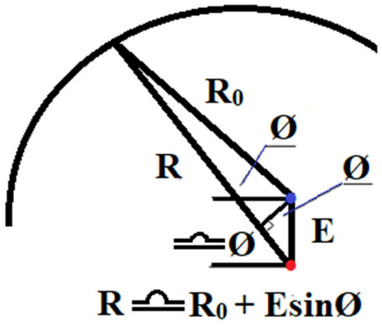

Fig. 11 Vector diagram for an alternative method of differential circumferential tensile forces calculation

Alternative vector diagram in which R is extended by the addition of E sinØ. As R_0 is smaller compared to R, the angles depicted by Ø can be considered as approx. equal.

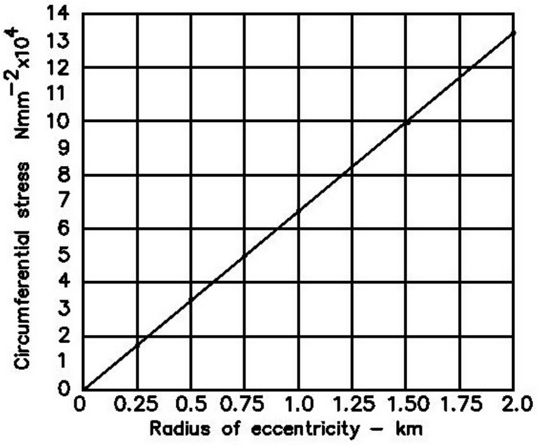

Fig. 12 Relationship between the radius of eccentricity (E) and the circumferential stress

It is also possible to look at the addition of the vertical component of E to the radius of the Earth to determine the expression of the forces in the direction of the maximum effective radius. Fig. 11 is used for this analysis. Fig. 12 shows the relationship between the radius of eccentricity and the circumferential stresses.

As above:

the mass of the segment $R\,\delta Ø = M\,R\,\delta Ø$

the radial force $F = \text{Mass}\ R\,\omega^2$

$= (M\,R\,\delta Ø)\,R\,\omega^2 = M\,\omega^2\,R^2\,\delta Ø$

Thus $\delta f = M\,\omega^2 R^2 \sin\O\,\delta\O$

With reference to Fig. 11 $R = R_0 + E\sin\O$

thus, $\delta f = M\,\omega^2 (R_0 + E\sin\O)^2 \sin\O\,\delta\O$

which approximates to

$\delta f = M\,\omega^2 (R_0^2 + 2E\,R_0 \sin\O) \sin\O\,\delta\O$

Thus, the increase of $\delta f = \delta f - M\,\omega^2 R_0^2 \sin\O\,\delta\O$

$= M\,\omega^2 (R_0^2 + 2E\,R_0 \sin\O) \sin\O\,\delta\O - M\,\omega^2 R_0^2 \sin\O\,\delta\O$

$= M\,\omega^2 \sin\O\,\delta\O\,(R_0^2 + 2E\,R_0 \sin\O - R_0^2)$

$= M\,\omega^2 \sin\O\,\delta\O\,2E\,R_0 \sin\O$

$= \mathbf{M\,R_0\,\omega^2\,2E\,\sin^2\O\,\delta\O}$ **(3)**

This equation has the same form as Equation (1) above. As E is small in comparison to R, and R_0 and R have essentially the same values, the factor 2 that appears in Equation (3) does not invalidate Equation (1). Hence the derivation of Equation (1) from the force diagram (Fig. 7a, b) is considered valid for determining Equation (2) by integrating between 0 and $\pi/2$.

Appendix 2:
Mathematical Analysis of Model 1—Unbalanced Flywheel approach (Figs. 4a, 5)

This analysis simply considers the Earth as an eccentrically rotating solid body such as an unbalanced flywheel in which the centre of rotation is moved away from the geometric centre. This differs from the model postulated for tectonic movements in which the COM is moved away from the centre of rotation. In both cases however, there will be an unequal distribution of the mass of the rotating body. This allows either vector diagram to be used to demonstrate the differential circumferential tensile forces.

Notations	**Values**
R = Radius (m);	6.4×10^6 metres
E = Eccentricity;	1.0×10^3 metres
T = Thickness	1.0×10^3 metres
ρ = Density (kgm^{-3});	2.8×10^3 kgm^{-3}
ω = Angular velocity (rad sec^{-1})	7.27×10^{-5} rad sec^{-1}
σ = Hoop Stress (Nm^{-2})	

Consider a cylinder of mean radius R and thickness T rotating at an angular velocity ω about its axis (Fig. 4a):

The mass of the portion $R\,\delta\O$ $= \rho\,R\,\delta\O\,T$

The radial force on the element $=$ mass × acceleration

$= (\rho\,R\,\delta\O\,T)\,R\,\omega^2$

This will produce the Hoop Stress $\boldsymbol{\sigma}$.

Resolving radially

$2\sigma\,T \sin\tfrac{1}{2}\delta\O = \rho\,R^2\omega^2\,T\,\delta\O$ (as $\sin\tfrac{1}{2}\O \rightarrow \tfrac{1}{2}\O$)

Therefore, the Hoop Stress $\boldsymbol{\sigma = \rho\,R^2\,\omega^2}$

If the centre of rotation is displaced δr, from the centre of mass (Fig. 4b) then the tensile force on the ‘heavier side’ will be increased by the following amount:

The increase in tensile stress

$= \rho\,\omega^2 ((R + \delta r)^2 - R^2)$

$= \rho\,\omega^2 ((R^2 + 2\delta r\,R + \delta r^2) - R^2)$

$= \rho\,\omega^2 (2\delta r\,R + \delta r^2)$

Substituting the above values:

The additional tensile stress

$= 2.8 \times 10^3 \times (7.27 \times 10^{-5})^2 \times (2 \times 10^3 \times 6.4 \times 10^6 + 10^6)$

$= 1.89 \times 10^5\,Nm^{-2}$

On the opposite side the decrease in the tensile stress will be as follows:

The ‘decrease’ in tensile stress

$= \rho\,\omega^2 ((R - \delta r)^2 - R^2)$

$= \rho\,\omega^2 ((R^2 - 2\delta r\,R + \delta r^2) - R^2)$

$= \rho\,\omega^2 (\delta r^2 - 2\delta r\,R)$

Substituting the numerical values, the tensile stress will have a negative value.

The tensile stress is thus

$= -1.89 \times 10^5\,Nm^{-2}$

This negative tensile stress is the compression stress which

$= -1.89 \times 10^5\,Nm^{-2}$

As stated above, the rigid body approach while clearly demonstrating the differential stress due to eccentricity is not considered as the model for tectonic movement. The model for tectonic movement as defined for Fig. 6 Model B and Fig. 7a, b, c is based on having relative movement between the outer rim or lithosphere and the main body or mantle.

Appendix 3:

The effect of Radial or Centripetal Forces on the Earth's Crust

From Appendix 2 consider 1 m^3 of crust with an average density of 2.8×10^3 kg m^{-3}.

Taking the same values used in Appendix 2
ρ = Average density of the crust 2.8 kg m^{-3}
M = Mass of 1 m^3 of element of crust 2.8×10^3 kg
R = Radius of Earth (m): 6.4×10^6 metres
Ω = Angular velocity (rad sec^{-1}): 7.27×10^{-5} rad sec^{-1}
Thus Fr = Radial Outward Force (N)

$$
\begin{aligned}
&= M\,\omega^2\,R \\
&= 2.8 \times 10^3 \times (7.27 \times 10^{-5})^2 \times 6.4 \times 10^6 \\
&= 94.71 \text{ N} \\
&= \text{c. } 9.65 \text{ kgf}
\end{aligned}
$$

Thus, for every 1 tonne of crust,
the outward force at the Equator owing to the rotational velocity = 9.65 / 2.8 = c. 3.4 kgf

This is equivalent to a 0.034% reduction in weight compared with that at the poles, where the rotational velocity is zero. This is enough to cause the lithospheric plates to move around the Earth surface on a frictionless mantle.