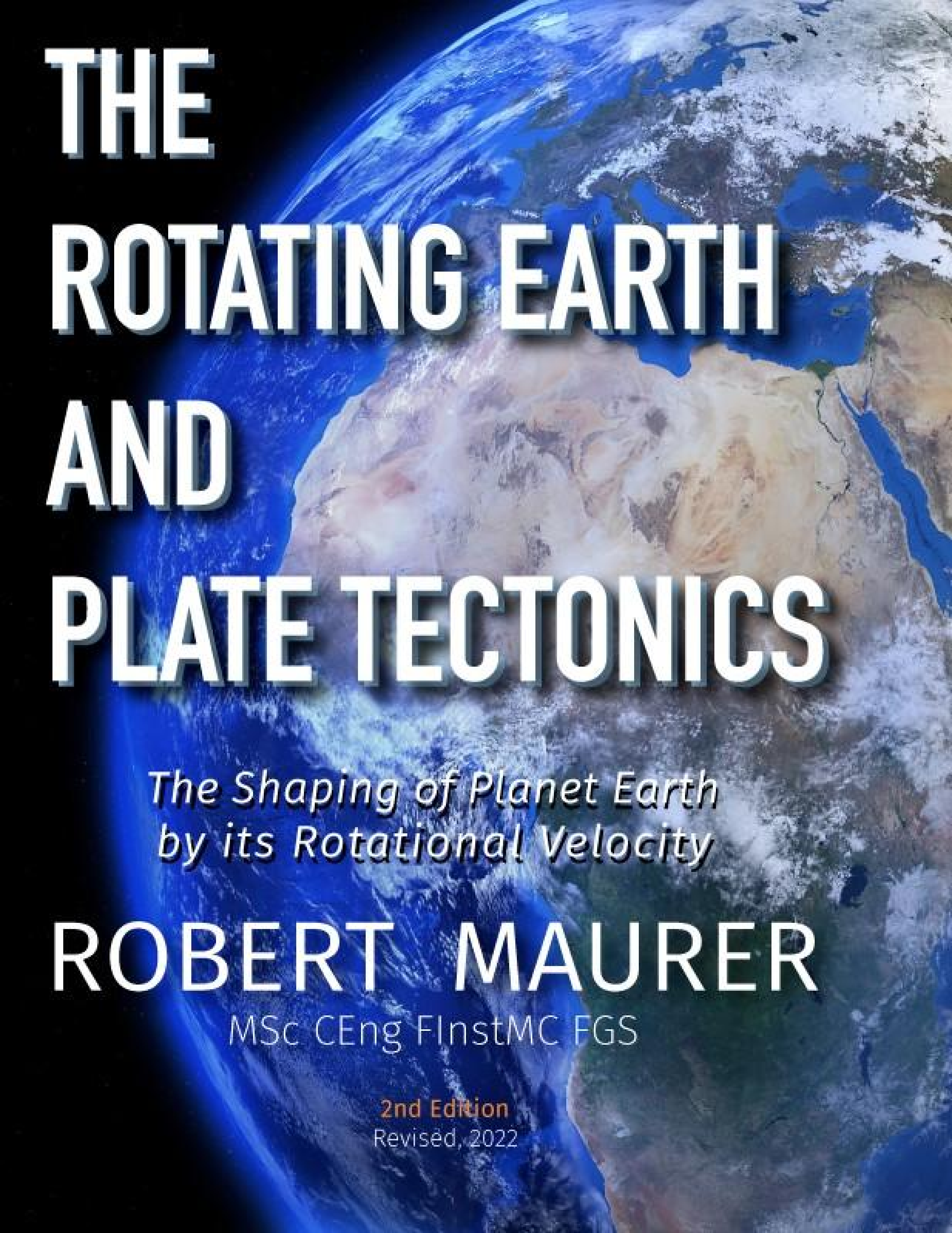

THE ROTATING EARTH AND PLATE TECTONICS

The Shaping of Planet Earth by its Rotational Velocity

ROBERT MAURER

MSc CEng FInstMC FGS

2nd Edition

Revised, 2022

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Birth of Tectonic Movements

that will regenerate the oceanic and continental lithosphere

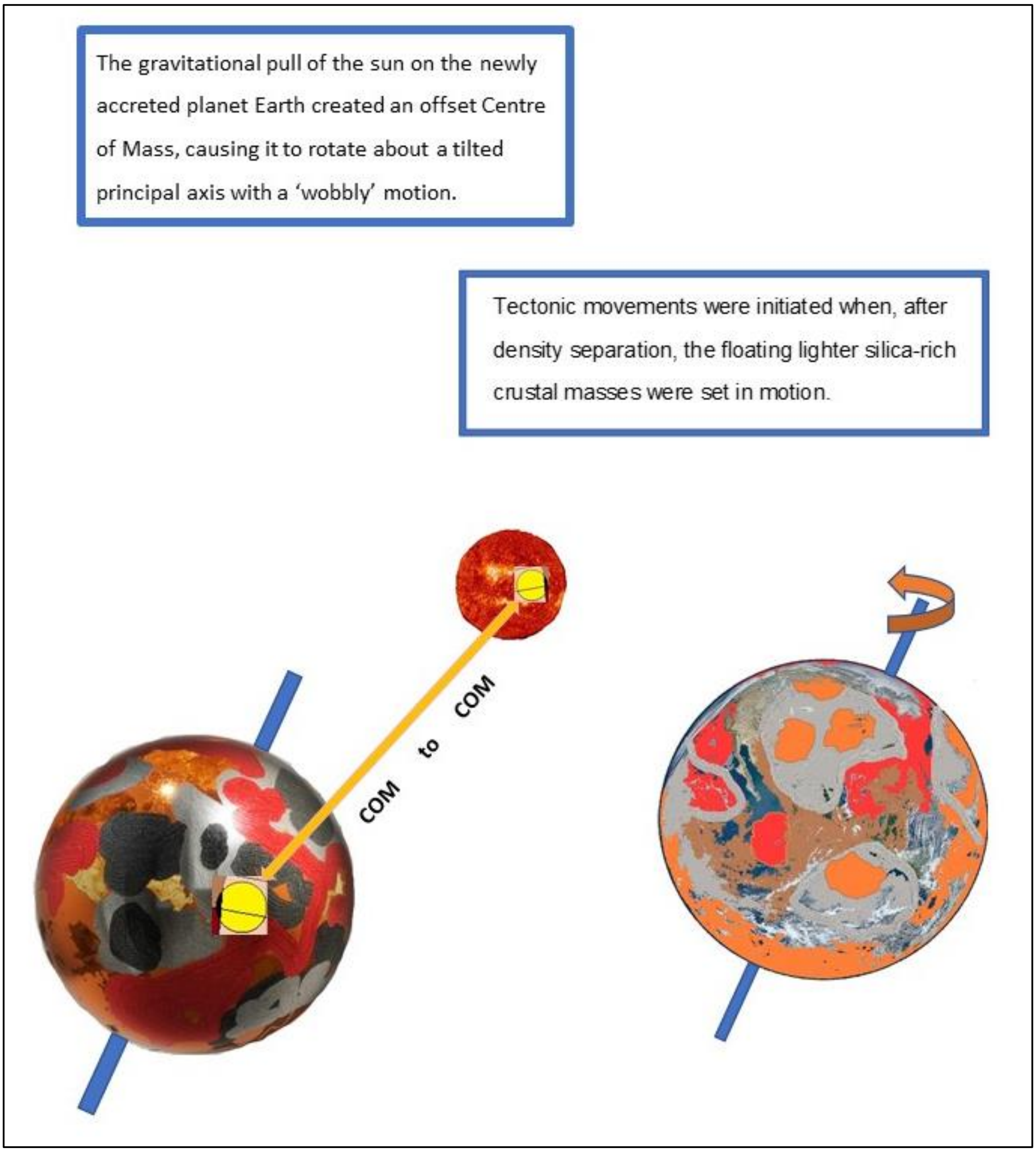
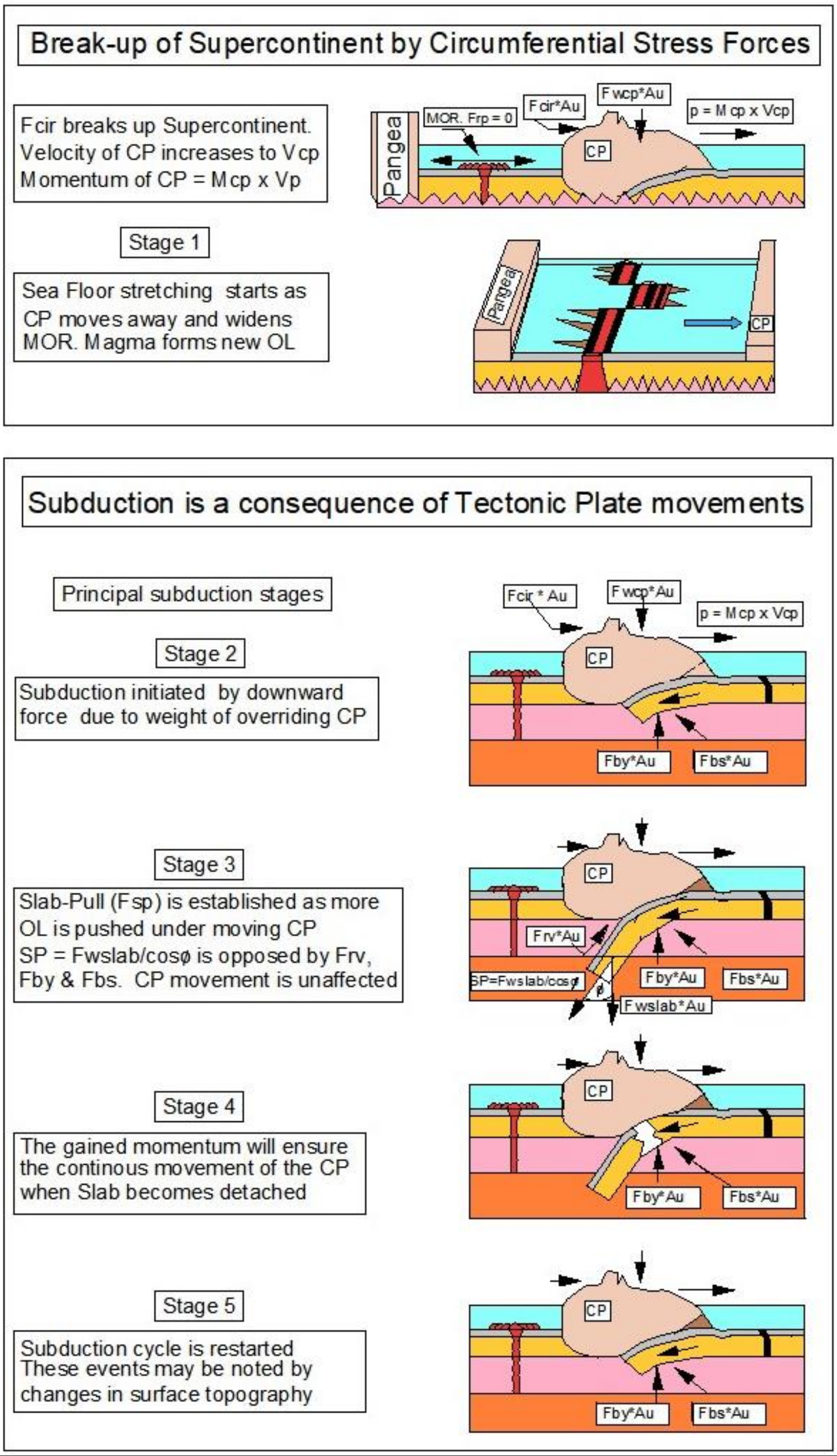


Fig iii. Taken from Section 7: A mutual gravitational pull will exist between the centre of mass (COM) of the Sun and that of the newly accreted planet Earth. For planetary rotation on its own axis to be initiated, the planet's COM must be pulled off-centre to provide leverage for a torque force.



The Separate Forces for Supercontinent Break-up and Subduction

Fig iv. Taken from Section 12: Circumferential tensile forces cause the break-up of a supercontinent. The movement of the continental plates initiates and sustains the process of subduction.

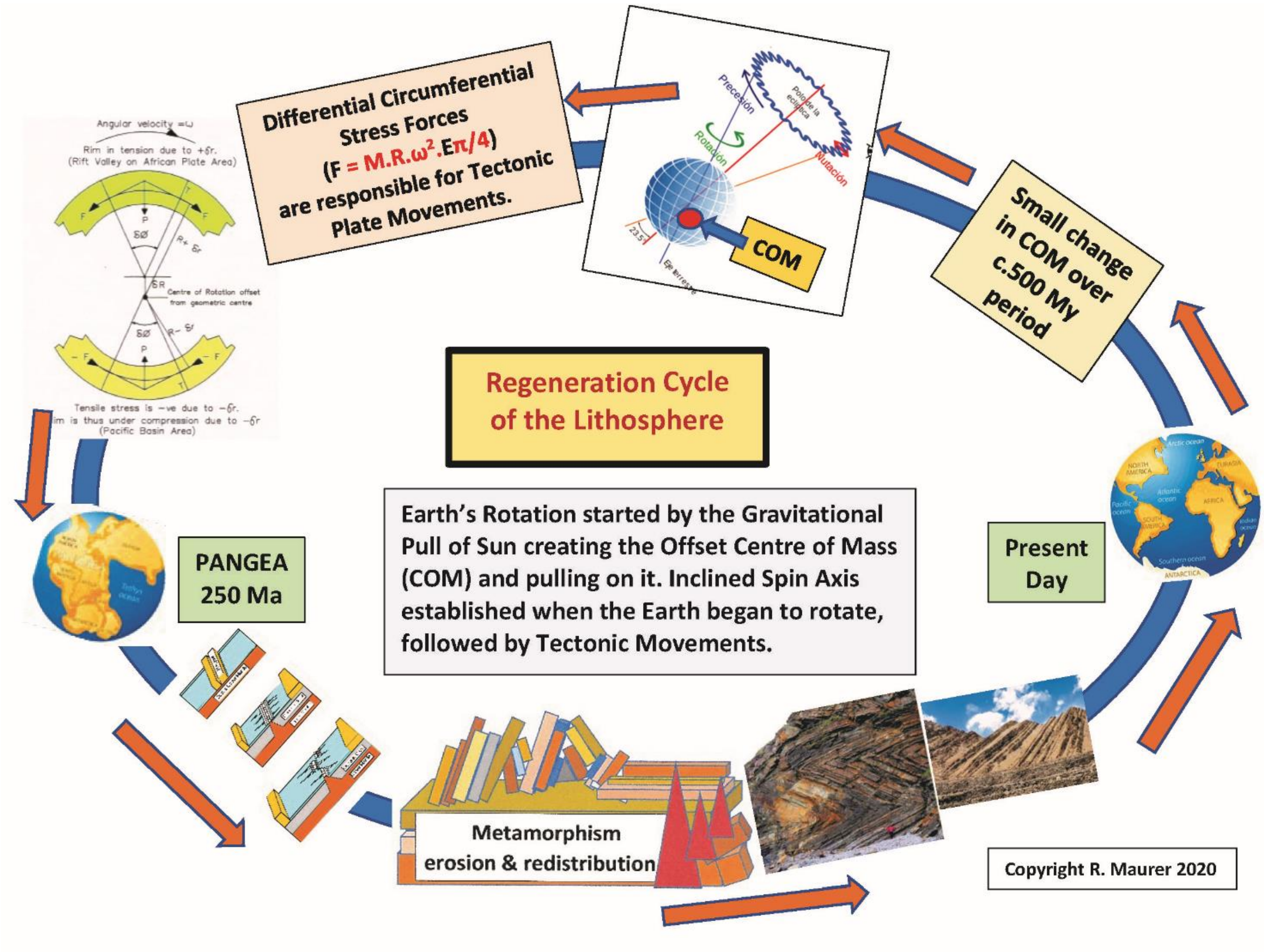


Fig v. Taken from Section 14: Sustained circumferential tensile forces both initiate the detachment of the continental plates from the supercontinents and maintain their movements, which result in tectonic processes and regeneration of the lithosphere

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Abstract

At present, there is still a lack of consensus regarding the mechanism responsible for initiating the subduction process and with it, the movement of the continental plates. By approaching this problem from an engineering perspective, this treatise offers a radical rethink of the problem by considering the 'wobbly' rotational motions of the planet Earth as indicated by the precessional movements of the tilted principal spin axis and the presence of the Milankovitch Cycles which closely mimic that of an unbalanced rotating body. The absence of a fixed axis of rotation does not affect the validity of this approach as Kepler's Laws of Planetary Motion clearly demonstrate the control of the planets' rotational and orbital behaviour by the gravitational pull of the Sun. This is in contradiction to the presently accepted view that the magnitude of these, often incorrectly termed 'inertial forces', are generally considered to be negligible in the context of tectonic plate movements.

By considering the Earth as an unbalanced rotating body with an offset centre of a mass (COM) it was 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 treatise will principally demonstrate that there is a separation of the forces acting to influence plate tectonics:

(A) The forces responsible for the break-up of a supercontinent, separately from
(B) The forces initiating and sustaining subduction.

Furthermore, the radical approach taken allows for the concept of 'momentum' to a moving continental plate (CP) to be introduced into this field of study. In this manner, it is possible to offer alternative explanations to the Hess heated circulatory convection current system, presently used to describe tectonic plate movements and subduction.

In developing this argument, the following points have been examined and discussed:

The positioning of the centre of mass (COM) of the Earth away from the axis of rotation (offset called the Radius of Eccentricity) giving rise to the tilt, its measured 'wobbly' motions as noted by the Milankovitch cycles and the precessional movements of the principal axis of rotation.

The development of the mathematical relationship describing the magnitude of the differential circumferential tensile forces in the outer rim as a function of the Radius of Eccentricity.

The creation of the principal N-S axis of rotation by the mutual gravitational pull of the Sun. This is extrapolated to the planets to discuss their common hand of rotation and similar tilt angles.

The introduction of the concept of 'momentum' to a moving continental plate (CP) and with it the initiation and prolongation of the subduction cycle.

The initiation of subduction of the oceanic lithosphere (OL), is shown to be a function of the downward forces created by the weight of the overriding continental plates. It is this action that forces the OL into the ductile mantle.

As the loss of the slab-pull force by the eventual detachment of the sunken oceanic lithosphere (OL) does not impede the movement of the CP, subduction has been shown to be a consequence of the movement of tectonic plates as distinct from being the driving force.

Convection currents in the mantle are thus shown to have a passive rather than an active role in tectonic plate movements.

The development of an alternative cycle of continuous lithosphere regeneration challenges the presently accepted Wilson cycle.

Contents

Illustrations and Figures

Acknowledgements

The sight of undisturbed sedimentary rocks on the top of the Bolivian Andes in 2001 prompted this research into the magnitude of the unrelenting forces associated with plate tectonics.

First Edition

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Extra thanks are given to Sandi Shallcross and Allan Wheeler for the editing and research on the extra topics addressed in this edition.

1. Introduction

The observation of the uplifted but almost totally undisturbed Palaeozoic to Cenozoic meta-basalt and turbiditic melange[39] beds reaching the top of the Andes near Potosi in Bolivia (Fig 1a & 1b) prompted the investigation into both the origin and the magnitude of the forces capable of lifting the western side of the South American continent from below sea level to up to c. 5 km above sea level.

Fig 1a

Fig 1b

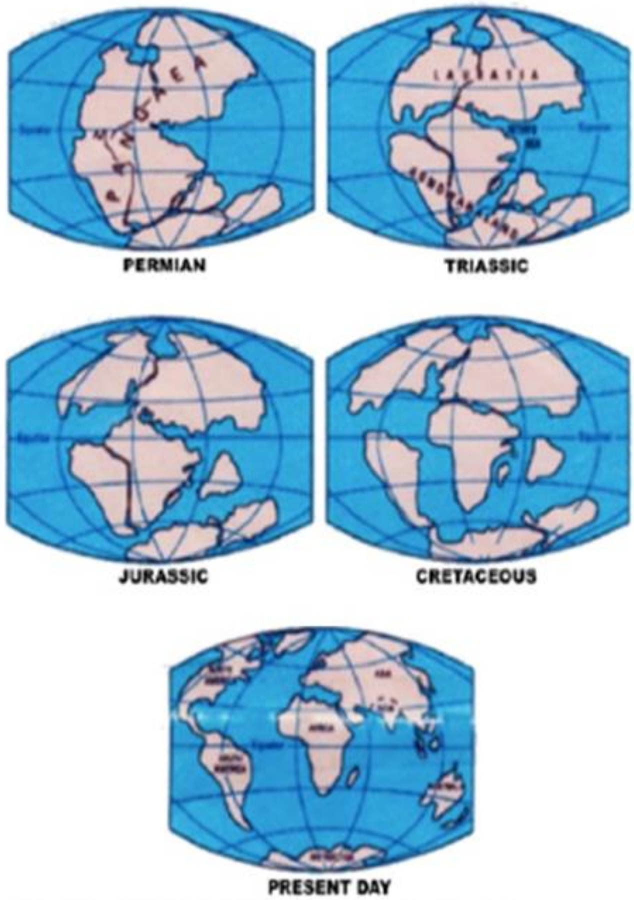


Fig 2 Breakup of Pangea, Permian to present day

A study[5,10,65-69] of the dispersal, beginning in the early Jurassic, of the major continental plates that formed the Pangea supercontinent, to their present-day positions (Fig 2) clearly demonstrates that the movements in different directions have been continuously sustained over a period of more than 200Ma. Current thinking is that the movement of a continental plate (CP) is the result of the 'pulling action' applied to it by the subduction of the higher density oceanic lithosphere (OL) as it descends below the CP. The direction of the heated convection currents considered to cause subduction must vary over time and distance as the CPs move apart. It was this inability to reconcile the long-term (millions of years) unidirectional movements of tectonic plates in an omnidirectional convection current-based force environment, that prompted the author (Maurer 2002) to examine the forces generated by the constant rotational velocity of the 'wobbly' planet Earth. The mathematical determination of the magnitude of the circumferential tensile forces subtended to the outer rim are demonstrated to be capable of breaking up a supercontinent. This has allowed for a comprehensive re-think of the tectonic forces that shape the surface of the Earth.

The literature survey has also shown that an approach based on the dynamics associated with an unbalanced rotating body or planet has not been exploited and has in fact been actively rejected[34,38] as a mechanism for tectonic movements. The rejection has been based on the assumption that the planets are freely rotating symmetrical bodies about their centres of mass (COMs), with minimum energy requirements and free of any torque moments. For Kepler's Laws of Planetary Motion to be obeyed, in which the Sun controls both the rotational velocity and the orbital paths of the planets around it, implies that the mutual gravitational pull is between the offset COMs of the Sun and the planets. This statement is reinforced by the fact that it is impossible to initiate and sustain rotation of a body about its centreline without an offset torque to impart motion. Under these circumstances the mathematical modelling of the Earth as an unbalanced rotating body, as presented in this treatise, is both creditable and acceptable.

The sustained movements towards both east and west, of the various plates away from the central and assumed almost stationary African plate suggests that the forces responsible for driving tectonic activity need to be constant and stable over millions of years. The obvious source must thus be related to the constant rotational velocity of the Earth. This view was reinforced by noting that the 'wobbling' Earth, with its change in the orientation of the inclined spin axis, the associated Milankovitch Cycles, the nutation (nodding motion) as well as the variable and cyclical 'Chandler Wobble', closely mimics that of an unbalanced rotating shaft whose 'Centre of Mass' (COM) is offset from its principal spin axis. An everyday example is the vibration of an unbalanced wheel on a motor vehicle.

By considering the 'wobbly' Earth as an unbalanced rotating body it is possible, by using the engineering approach of rigid body dynamics[2,7,26,29], to estimate the circumferential tensile forces capable of splitting up a supercontinent in the thin outer rim of the Earth. This is made manifest by the development of the following equation relating the circumferential tensile stress (F) to the distance between the COM and the centre of rotation. This distance is now referred to as the Radius of Eccentricity (E). This is denoted by the equation

$$F = M\,R\,\boldsymbol{\omega}^2\,E\,\pi/4$$

where F = circumferential tensile stress, M = mass of segment of the Earth, R = radius of the Earth and $\boldsymbol{\omega}$ =Earth's rotational velocity.

It was further noted that the tectonic plates on separating from the already mentioned central almost stationary African plate accelerated from zero velocity (Vo) to moving plate velocity (Vp). In doing so, the tectonic plates acquired momentum which is defined as the product of mass and velocity.

$$\text{Mass} * \text{Velocity} = Mcp *(Vp - Vo) = Mcp * Vp$$

Although the velocity is small, the mass is very large, and the overall momentum is such that the moving plate can only be halted by collision at a convergent margin. The creation of the Himalayas is a prime example

It thus became obvious that subduction of the oceanic lithosphere is initiated by the downward force due to the weight of the overriding continental plate. This led to the logical and unexpected conclusion that continental plate movements are independent of subduction and, by implication, of slab-pull forces, in that the presence or absence of slab-pull does not appear to impede CP movement.

As such the forces associated with heated convection currents are now seen as being modified by tectonic plate movements rather than the driving force. This is a major change in the study of plate tectonics.

In Summary

The positioning of the centre of mass (COM) of the Earth away from the axis of rotation (Radius of Eccentricity) makes it possible to offer viable explanations for the creation of the N-S principal axis of rotation, its tilt and the oscillatory movements of our 'wobbly' planet Earth as noted by the Milankovitch cycles. It is conceivable that this situation may be extrapolated to the planets in that they all (Venus apart - which may be upside down) display a tilt and have the same anti-clockwise rotation as has the Sun and Earth.

The development of the mathematical relationship describing the magnitude of the differential circumferential tensile forces in the outer rim as a function of the Radius of Eccentricity, allows for the estimation of these tensile forces that are capable of the breaking up of a supercontinent.

The introduction of the concept of the momentum to the moving continental plates and with it the initiation and propagation of the subduction cycle by the downward force due to its overriding weight allows for a complete re-evaluation of the separate forces responsible for tectonic movements and subduction.

This treatise separates the forces responsible for tectonic movements from the forces responsible for subduction

Convection currents in the mantle are thus shown to have a passive rather than an active role in tectonic plate movements.

This approach also allows the development of an alternative cycle of continuous lithosphere regeneration that challenges the presently accepted Wilson cycle.

2. Current Theory of Plate Tectonics

2.1 Pioneers of Plate Tectonics Theory

The remarkable fit of South America to Africa had been remarked on ever since coastal outlines had been mapped. In 1912 Dr Alfred Wegener[74] (Germany) published his Theory of Continental Drift based on fossil and meteorological similarities in the Americas, Africa and parts of Northern Europe. He postulated that all the Continents had been joined together in one landmass, which he termed Pangea (Greek for one land – entire Earth) (Fig 3). Wegener was a meteorologist, not a geologist, and his observations were not given serious consideration by the professional geologists at the time.

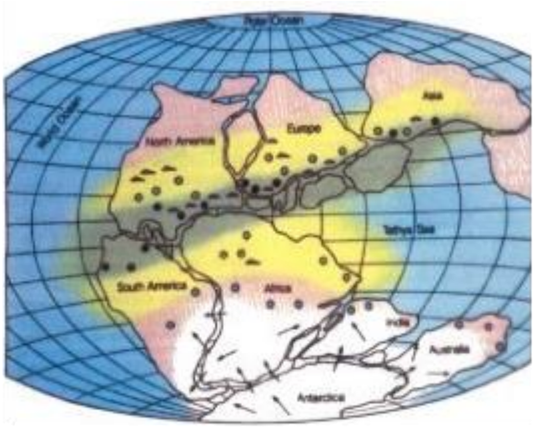


Fig 3: Pangea, c.300-200 Ma

In 1937, geologist Alexander du Toit (South Africa), published his book 'Our Wandering Continents'[65] which broadly supported Wegener, and proposed two continents, Laurasia and Gondwana which later collided to form Pangea. His geological evidence included the comparison of tillites and fossils in South America and South Africa. His detailed work also allowed him to demonstrate that the Caledonian Mountains, formed during the Caledonian Orogeny, ran continuously from Scandinavia, via the British Isles and East Greenland to the Appalachian Mountains in the Eastern USA, until split by the break-up of Pangea.

Du Toit coined the terms Gondwanaland, Laurasia, and Tethys Sea to add to Pangea. Despite the overwhelming evidence, this work was not fully accepted, as du Toit, like Wegener before him, did not offer a mechanism to explain how the continents drifted apart and together.

In 1944 Arthur Holmes[26,27] first published the proposal that heated convection currents in the mantle, owing to the heat generated at the core, could provide the mechanism to account for orogenic activity. However further evidence was needed to sway the many sceptics.

During the 1950s and 1960s, new evidence, particularly with regard to palaeomagnetism and seafloor mapping using sonar and seismic measurements, showed that the observations could only be accounted for if the continents moved over the surface of the Earth if Pangea had existed and continental drifting had occurred[66,67]. The ocean floors were found to have bands of reversed magnetic polarity in a striped and mirrored pattern about a raised mid-ocean ridge (MOR)[72] (Fig 4). The ages of the basalts ranged from the Jurassic, most distant from the ridges to the present, such as in Iceland. Palaeomagnetism showed that the poles had apparently been in different places in different continents, only possible if the continents themselves had moved.

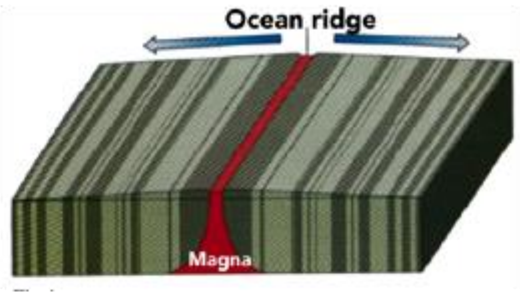


Fig 4: Magnetic polarity reversals on the ocean floor.

Prof. Harry Hess (Princeton USA) checked these new discoveries against his own meticulous mapping of the Pacific Basin during his tenure in the US Navy in WW2. He identified the topography of mid-ocean ridges and the abyssal plain, with deep trenches close to continental margins.

In 1962 Hess published 'The History of Ocean Basins'[25] in which he linked the Pacific Basin's deep trenches to destruction and recycling of oceanic crust through the generation of magma that issued from continental volcanoes, and the creation of new oceanic crust at the mid-Atlantic ridge (Fig 5). He concluded that the breakup of Pangea and subsequent continental or plate movement was due to the combined action of 'ridge push' forces at divergent boundaries (Fig 2) with the 'slab-pull' forces at convergent boundaries. In this manner, Hess was able to balance the creation of new oceanic crust by the equivalent subduction of older oceanic crust. He attributed the forces involved in the action of heated circulation currents within the Earth's mantle.

A paper published in 1963 describing "Magnetic anomalies over ocean ridges", subsequently known as the Vine-Matthews-Morley hypothesis[72], described the patterns of magnetic reversal in ocean basalts. This demonstrated the symmetry of ocean spreading and allowed measurement of the rate of plate movement away from mid-ocean ridges.

In 1965, John Tuzo Wilson[66, 67] (Canada) proposed 'transform faults' which linked divergent plate boundaries at ocean ridges to convergent boundaries at subduction zones. They provide a mechanism whereby spreading of adjacent segments of oceanic crust can be accommodated by horizontal movement.

Dan McKenzie[38,39] applied thermodynamics to the problem of convection and published "The viscosity of the Lower Mantle" in 1966, opening the way to subsequent models for plate tectonics.

The next breakthrough came in 1979 when the experimental submersible *Alvin* mapped the Mid-Atlantic Ridge and observed the creation of new oceanic crust at 'black smokers' along the ridge (Fig 5).

These discoveries and subsequent research all contributed to the current Theory of Plate Tectonics based on a cycle of creation and destruction of oceanic crust and continual plate movements, accompanied by mountain building and metamorphism.

Fig 5

Finally, 30 years after he died, Wegener was credited with being the father of the science of Plate Tectonics.

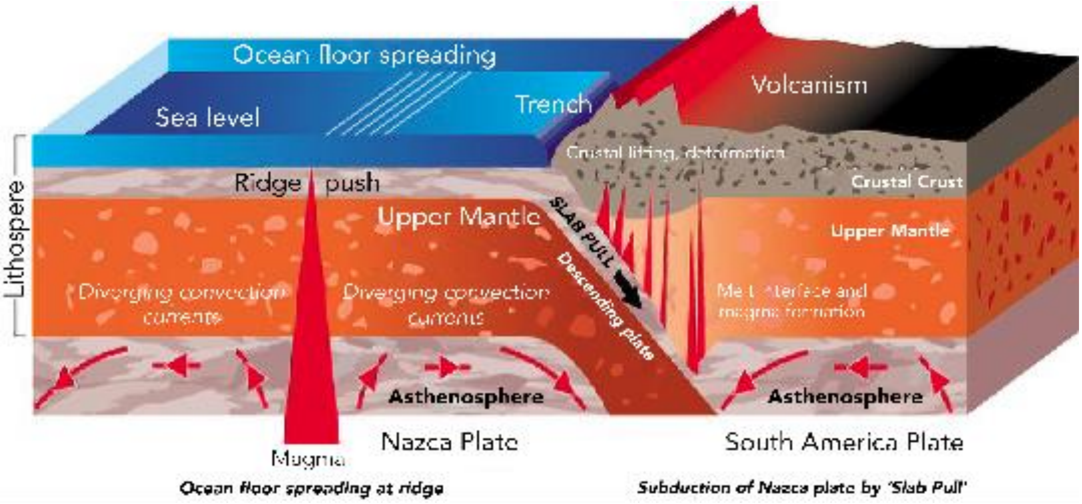
2.2 The Limitations of the Hess Model

The model[3,25] shown diagrammatically in Fig 6 suggests that the subduction of the colder and denser oceanic crust into the mantle by 'slab pull' forces resulting from gravity and convection currents in the upper mantle is the major force responsible for driving continuing tectonic plate movements. This 'slab pull' force is also linked to the recycling of oceanic crust at deep ocean trenches at convergent plate boundaries and orogenic and volcanic activity within the overriding plate.

The force attributed to 'Ridge Push' at spreading ocean ridges[17,22,38.50,63] is now considered to be insufficient to generate significant plate movement. The lack of distortion, other than at the transform faults, of the stripes showing magnetic reversal on either side of the mid-ocean ridge (Fig 4), demonstrates the absence of a lateral push force, which would be expected owing to the discontinuous nature of MOR spreading.

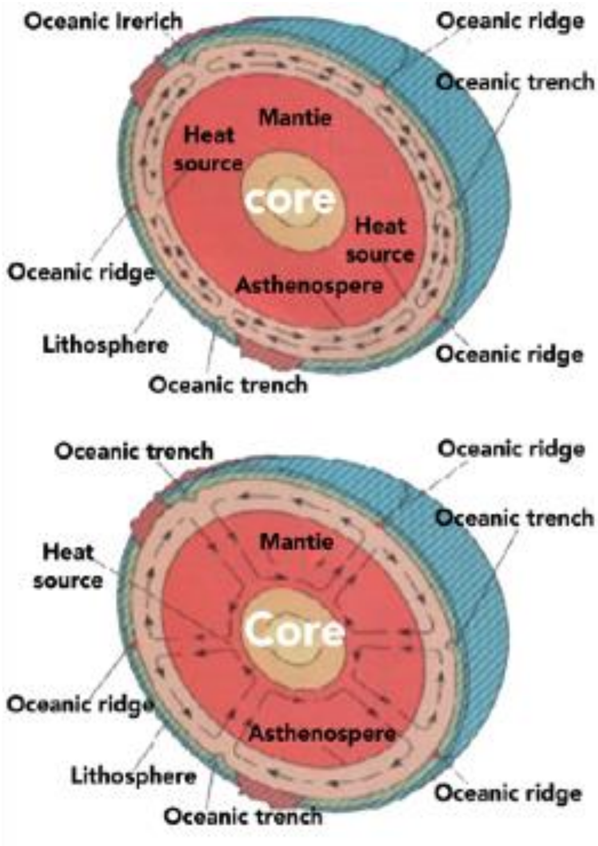
It is surprising and puzzling, therefore, that with this high level of agreement[16,18,34,46,75] regarding convection currents as being the major driving force for plate movement and subduction, there is an absence of a magnitude 'action-reaction' mechanical force diagram which unambiguously represents the 'slab pull' force vector.

Fig 6



There is still no generally agreed model of convection currents in the mantle and the role and origin of mantle plumes is hotly debated. Two proposed circulation systems[6,18] are summarised in Fig 7.

Fig 7



Although this paper investigates the rotational velocity-derived circumferential stress forces as the primary cause of tectonic and orogenic activity, a brief discussion on some aspects of convection current-driven plate movements is considered relevant. Dewey[11,12], van Andel[68,69], and Davies[9] 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 basically 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 mode from the equatorial 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.

However, as the African plate has been relatively stationary, the north-south convection currents must have moved the present Indian plate in a north-north-east direction into the Eurasian plate.

This implies that the opposing heated convection currents must have been, and still are, stable over the 140 Ma period since the end of the Jurassic (Fig 8).

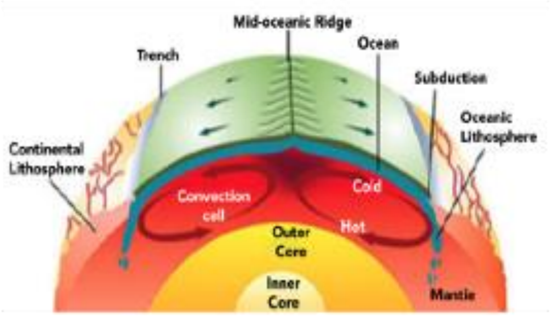


Fig 8 Convection requirement for 140 Ma

It is interesting to note that Davies[8] states that, as the plate near the pole of rotation may be rotating about a vertical axis relative to the mantle, it would be inaccurate to think of the mantle motions in terms of simple roll cells of convection. In a spherical shell, the flow may need to connect globally in a complex manner. Davies[8] also summarises other contemporary work which suggests that the 'return flow' from subduction under the north-west Pacific back to the East Pacific Rise may pass under North America. This would approximate to a great circle path, with the flow under North America probably having a southerly component that would not be inferred from the local part of the plate system. A further difficulty arises when trying to understand 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 in mainly east and west directions alongside the simultaneously north- and north-eastward clockwise rotation of the Indian and Australian plates (often referred to as the Indo-Australian plate). Nor can the existing current convection hypothesis reconcile the variation in the velocity of the different plates as illustrated by Park[50] and Hamblin[23]. Overall, it is difficult to reconcile the sustained unidirectional movements of the various continental plates from their positions as part of Pangea over 275Ma ago to their present positions, with the clearly omnidirectional convection current flow patterns.

2.3 The Andean and Himalayan Orogenies

It is obvious that the forces involved in pushing up the Andean Mountain range to as high as 5,000m above sea level has been, and still is, continuously sustained in one direction. The direction of the forces will be perpendicular to the alignment of the mountain chain. In this case, where the collision is between continental and oceanic crust, the uplift of the Andes is attributed to the noted subduction of Nazca oceanic crust by the 'slab pull' mechanism[24].

In contrast, the continuing uplift of the Himalayas (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 and Davies discuss this matter in some detail. From the purposes of that article's point of view, 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 this treatise, momentum considerations are used to explain the NE movement of the Indian Plate and its collision with Eurasia.

3. Rotational Behaviour of the Earth

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 behaviour of the planet. Waller & Home[73] considered the rotating Earth as a non-homogenous shell that comprises an inner mantle which in turn surrounds a semi 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[55] described 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, Koppers, Kearney and Vine[30] as well as Courtillot and Besse[7] suggested that this phenomenon might be the result of changes, in the Earth's principal axis, of inertia caused by the redistribution of mass in the mantle. The literature survey did not uncover viable agreed explanations regarding both the origin of the variable tilt angle of the Earth's axis (22.1°-24.5°) as well as the reasons for the Milankovitch[41,42] precession movement cycles (Fig 9).

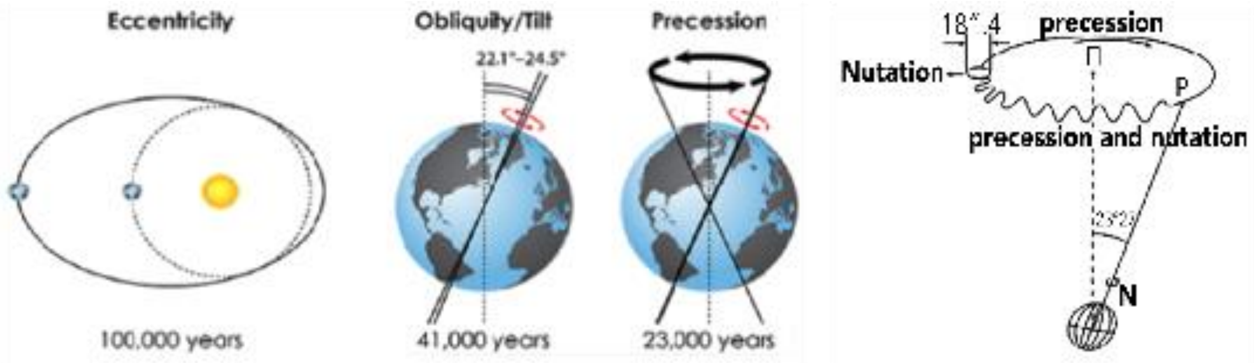


Fig 9 Cyclical changes in the Earth's spin axis

Laskar et al.[33] suggested that:

> The gravitational pull of the Moon on the Earth has stabilised the tilt deviation to the order of 1.3° and
>
> The absence in the case of Mars of a stabilising gravitational force by a relatively large moon has allowed its axial tilt to vary from 10° to 60° over tens of millions of years.

Following the observations of the uplifted sedimentary sequences in the Andes (Fig 1a & 1b), it became apparent that the forces associated with the continuous unidirectional northward movement of Pangea from the Permian to the Jurassic, followed by the westward movement of the American plates and the north-east movement of the Indian and Australian plates (over 275 Ma), would have to be constant over this large geological time span.

It was this observation that prompted the investigation of the forces associated with the constant rotational velocity of the Earth. The most notable observations were the Milankovitch cycles which display cycles in:

a) The variation in the eccentricity of the Earth's orbit[41] (over 100,000 years)

b) Oscillations in its degree of axial tilt between 21.5° 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 behaviour of a rotating shaft with an unbalanced load[4,35]. The 'Chandler Wobble' (3-15 metres at the North Pole) which is superimposed on the other wobbling motions has a rotation period of 433 days. The wobble is not unlike that of a spinning toy top. The following simplified diagrams are given to demonstrate the similarity between the end motions of the unbalanced shaft and the Milankovitch cycles. Fig 10 shows the damaging effect on journal bearings supporting an unbalanced tilted shaft rotating around its mass centre rather than the intended geometrical centre. Fig 11a shows the torque forces that surround the unbalanced rotating body trying to change the rotational axis to accommodate the offset centre of gravity. Fig 11b shows the end view of the elliptical path taken by an unbalanced rotating circular body and the instrumentation surrounding it, to compute the position and magnitude of the counter-balance weight needed to affect balance and remove the inclined tilt. This motion plotted in Fig 11c shows 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. Fig 11d shows a typical plot of the vibrational movement along the length of the unbalanced rotating shaft and Fig 11e will show the animated vibrational motions in a Power Point presentation[64]. An everyday example is the balancing of a motor vehicle wheel from the measurements taken at the 'C' & 'K' positions (Fig 11b) to ensure a smooth ride when a new tyre is fitted. 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, motor armatures, etc. These equations are also well documented in almost every textbook on applied mechanics[33,44,54].

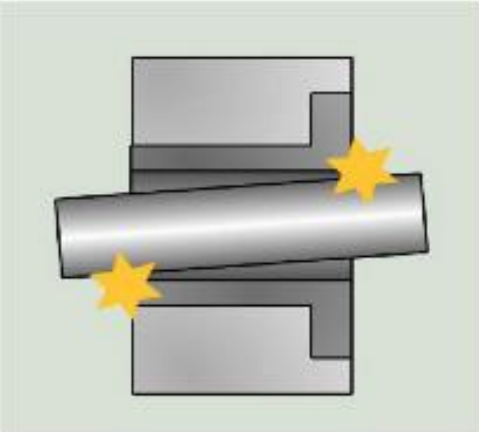


Fig 10

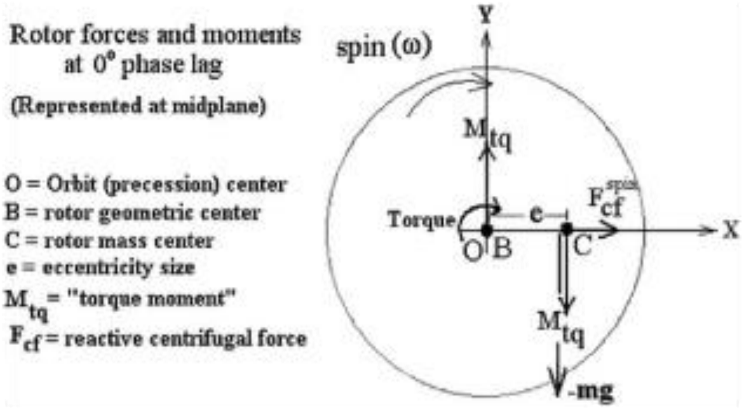


Fig 11a

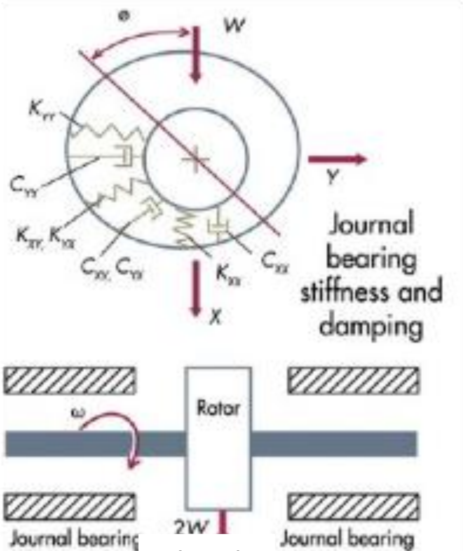


Fig 11b

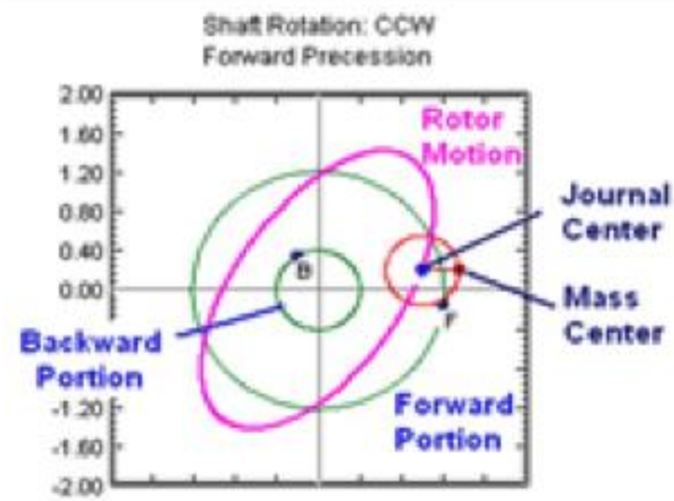


Fig 11c

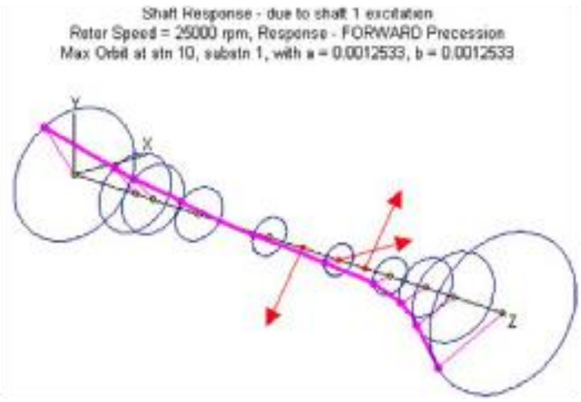


Fig 11d

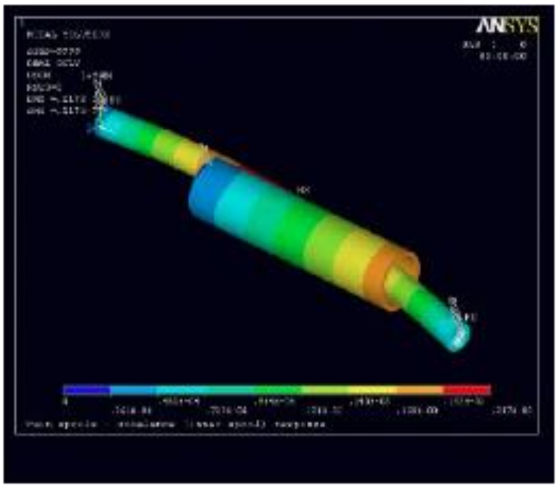


Fig 11e

4. Positioning the Centre of Mass and the Axis of Rotation

In trying to determine a possible source or cause responsible for the planet behaving like an unbalanced rotating body, some principal features of global tectonic activity need to be 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. It thus seemed sensible to try and determine the COM of the Earth and use that value to estimate the 'differential circumferential stress forces' (DCSF) created in the Earth's lithosphere.

With reference to Fig 12, the following observations are noted: (a) the geologically quiescent African plate shows the characteristics of being in tension in that while there no evidence of subduction (except in the north), splitting of the plate is taking place at the Rift Valley. In contradiction, (b) the Pacific Basin with its deep peripheral trenches, crumpled topography (west of the Hawaiian chain) and subducted areas of the lithosphere (e.g., the Nazca plate under the South American plate) has all the appearances of being in compression. If, as postulated above, the Pacific Basin is under compression whilst the African plate is under tension, then an unbalanced rotating body model requires the COM to be positioned east of the spin axis (as we view Fig 13) but 'west' of the Rift Valley.

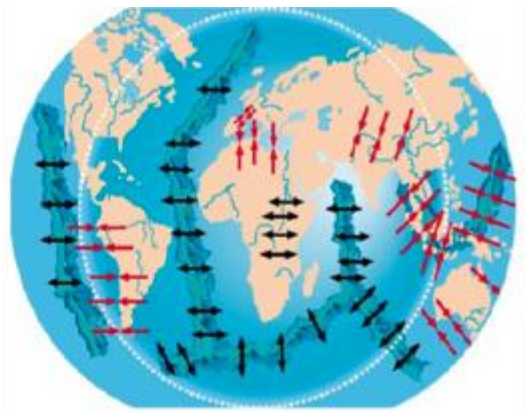


Fig 12

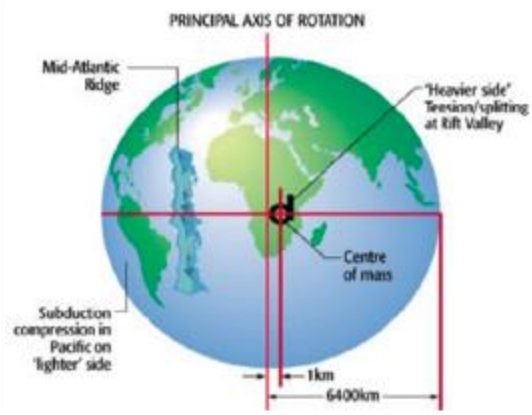


Fig 13

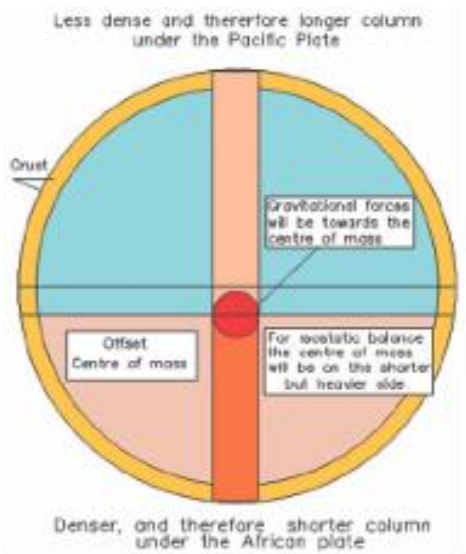


Fig 14

This is in keeping with the mechanics of rotating unbalanced bodies (as described in Section 5 and annotated in Figs 18 & 20), in which the 'lower mass' side will be in compression, and the 'higher mass' side will be in tension. In attempting to determine the possible position of the COM, consideration was given to the physics relating to the phenomenon referred to as isostatic equilibrium.

Essentially, isostatic equilibrium calls for the balancing of forces (associated with different weights on different areas) acting against each other through a fluid column. A hydraulic jack is a common everyday example. In the case of Earth movement, isostatic equilibrium is associated with the balancing of forces due to different weights of landmasses in proximity. An example is the post last ice age net uplift (rebound) in Fennoscandia which is still rising by up to 8 to 10 mm yr^{-1} following the disappearance of the Northern European ice sheet[60]. This reached its maximum volume c.23,000 years ago, depressing the crust/mantle under its weight. If this principle can be invoked on a global basis (Fig 14), then the 'column' supporting the lighter Pacific plate will need to be taller than the opposing 'column' supporting the heavier African plate with its larger mass of continental crust. In doing so, the following equation can be derived to give a simple approximation of the position of the COM by considering the difference in average elevation between the oceanic crust of the Pacific Basin and the continental crust of the African continent to be 8 km. For ease of explanation, the densities of the mantle and outer core is assumed to be constant. For simplicity the head of water in the Pacific Basin has been ignored as the African plate is surrounded by water as well. As the calculations are based on the offset of the COM being 1 km the variation owing to the heads of water does not make a significant impact on the argument.

Taking rounded values, we have:

Average elevation difference between the Pacific Basin and African continent = 8 km

R = radius of Earth = 6,400 km

ρ crust = density of crust = 2.8×10^3 kg m^{-3}

ρ core = density of the core = 10.7×10^3 kg m^{-3}

X-sectional area of columns = 1 km^2

E = distance (km) from the core centre to the balance point

Thus, the weight of the 1 km^2 Pacific column to the balance point

$= (6{,}400 - 8) \times 1 \times 2.8 + E \times 1 \times 10.7 = 17{,}897.6 + 10.7 \times E$

Similarly, the weight of the 1 km^2 African Column to the balance point

$= (6{,}400) \times 1 \times 2.8 = 17{,}920.$

Solving for E, at the balance point we get $17{,}897.6 + 10.7 \times E = 17{,}920$

This resolves to give ~~the~~ $E = (17{,}920 – 17{,}897.6) / 10.7 = 2.09$ km

As an example, for ease of calculating the circumferential forces at the Earth's surface, the COM E is placed 1.0 km off-centre from the axis on the African plate side. Although this extremely small but feasible displacement of the COM from the centre of rotation is of the order of 0.5 to 1.0 Km, or 0.015% of the Earth's radius, the actual magnitude of the subtended surface forces as shown by the analysis are substantial. This is explored in Section 6.2.1.

5. Kepler's Laws and Unbalanced Rotating Planetary Bodies

The proposed mathematical models relate the magnitude of the circumferential forces in the outer rim to the unbalanced Earth rotating about its geometrical centre with the COM being offset from the axis of rotation. This assumption has met with resistance on the basis that the generally held consensus is that the Earth and other planets are considered as freely rotating bodies about their COM which is co-incident with their axis of rotation. Using these assumptions, the moment of inertia would be zero as would be any subtended forces at the surface of the planet. There is thus a notable absence of serious published study on this subject. The literature survey has also shown that an approach based on the dynamics associated with an unbalanced rotating body or planet has not been exploited and has in fact been actively rejected[34,38] as a mechanism for tectonic movements.

This requirement is made manifest when applying Kepler's Laws of Planetary Motion which clearly shows how the Sun controls both the orbital and rotational velocities of the Earth particularly as the Earth moves in an elliptical orbit (as do the other planets). Consideration of Kepler's Second Law regarding the variable gravitational pull of the Sun on the Earth (Fig 15a) as it moves through a complete elliptical orbit clearly demonstrates the cyclical speeding up and slowing down of the orbital velocity. This occurs both on the movement towards and away from the perihelion. Planetary movements are thus directly controlled by the mutual gravitational pull between the planets and the Sun and as such they cannot be considered as freely rotating bodies. These motions (Fig 15b) as set out by Steiger & Bunton in the California Institute of Technology (Caltech) publication (ref. below) clearly demonstrate that the Earth in describing an elliptical orbit must rotate 360 degrees plus a small angle (timed at 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 (timed at minus 7.7 minutes) to ensure it remains 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.

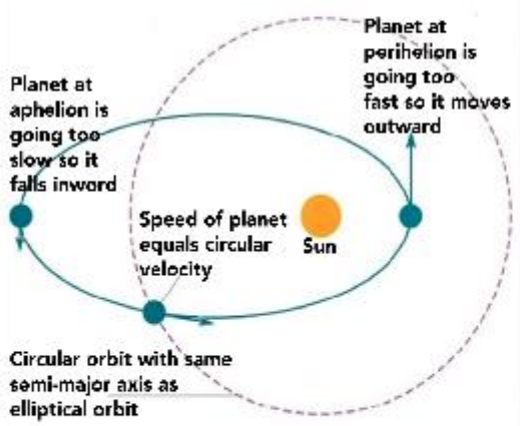
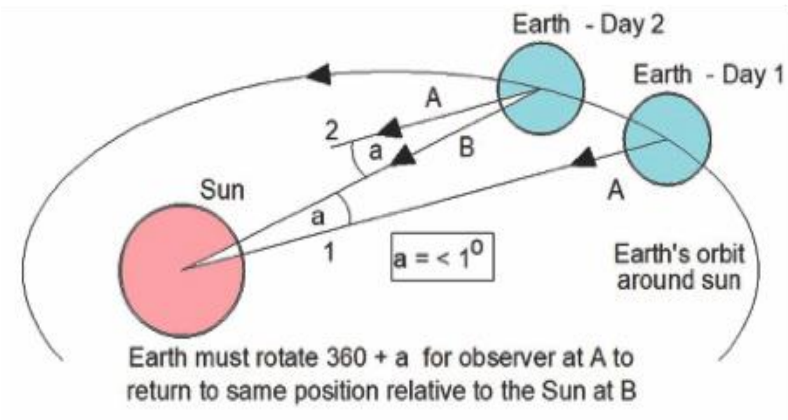


Fig 15a

Fig 15b

The Earth moves slowest at A and fastest at BWG Steiger, Caltech http://www.cso.caltech.edu/outreach/log/NIGHT DAY/elliptical.htm



As it is impossible to rotate a body about a dimensionless centreline, an offset torque moment must be applied. 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. The offset COM of the Sun is discussed. This concept as illustrated in Fig 16 shows the movement of a circular object on a spindle via an offset torque force.

Fig 16 Rotary hand quern with offset handle

The opposition to the validity of mathematically modelling the Earth as an unbalanced rotating body, proposed by the Author in 2002 and opposed via peer review on the basis that the Earth and the other planets are considered as ‘freely rotating bodies about their centre of mass with zero Moment of Inertia’, and are thus independent of the gravitational pull of the Sun, is unfounded. As such the mathematical model used in this treatise should be both acceptable and viable.

This concept also brings with it the exciting and unexpected conclusion that the COMs must be ‘off centre’ in order that the gravitational pull from the Sun, acting on the offset COM, will in fact provide a torque moment to effect rotation, and in doing so, the principal N-S axis of rotation of an unbalanced rotating planet is established. This treatise postulates that the offset COM was created when the Sun captured the accreted mass that would become the planet Earth at the development stage of the Solar System (Birth of Tectonics, page 2). This approach has been extrapolated to the other planets and may well explain why all the planets in the Solar System (except Venus which may be upside down) rotate with the same hand and in some cases with a similar daily rotation period.

This approach may also explain that the extremely low rotational velocity of the planet Mercury (58.646 Earth days = 1407.5 Earth hours) compared to <25 hours for the other six planets except Venus (243.023 days) is due to the possibility that the COM and the axis of rotation are almost co-incident. This is noted by Mercury’s small tilt angle of 2° and thus a noticeable absence of an offset COM for the Sun’s gravitational pull to act upon. (https://solarsystem.nasa.gov/planets/mercury/in-depth/)

The gravitationally driven unbalanced rotating planets with their offset COM’s will also tilt towards the heavier side and vibrate or ‘wobble’. An everyday example is the need to re-balance a vehicle wheel after fitting a new tyre. This ‘wobbling’ action of the planet Earth will manifest itself by the oscillatory behaviour of its axis of rotation and is noted as one of the Milankovitch cycles.

It is noted from Fig 17 that all the planets have a similarly inclined axis of rotation to a greater or lesser degree (except Uranus on its side and Venus upside down). As their rotational velocity is driven by the Sun’s gravitational pull on their ‘offset COM’s’, they should all exhibit Milankovitch type oscillatory cycles. At present the ‘wobbles’ on the other planets have not yet been observed, except for a Chandler wobble recently discovered for Mars[31A].

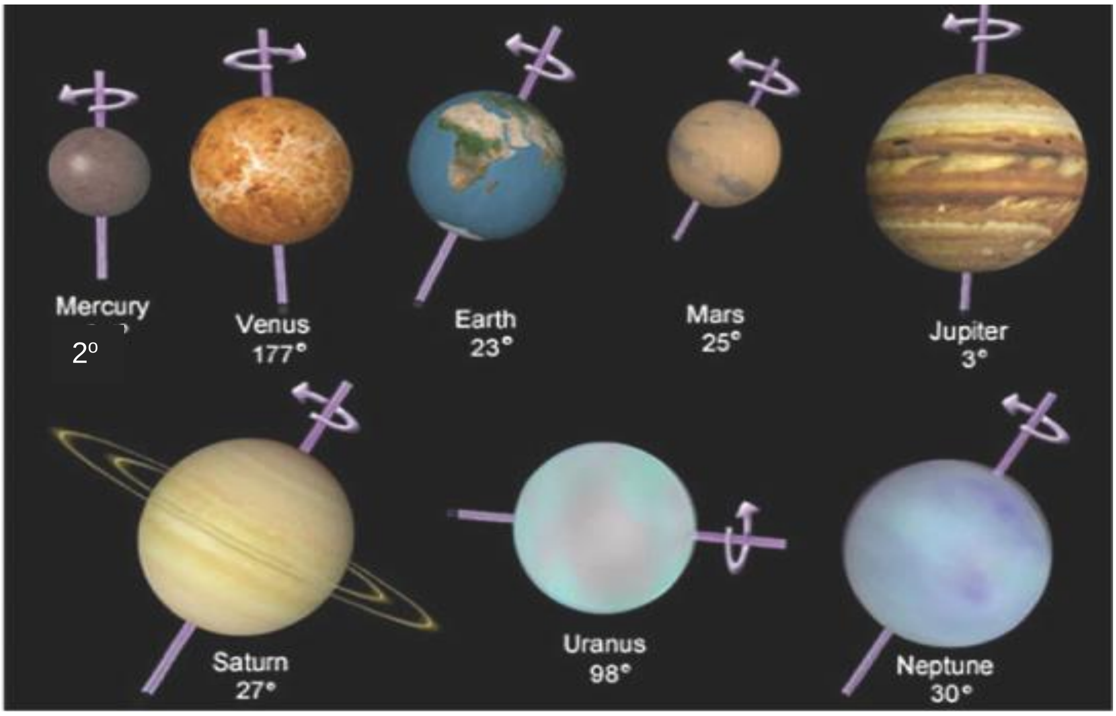


Fig 17 Rotational axes of the Planets

5.1 Discussion – Consideration of the offset COM in relation to tectonic processes

This conceptual research work investigating the forces capable of breaking up a supercontinent (Pangea is used as an example) and sustaining the unrelenting unidirectional movements of the separated tectonic plates away from the central 'heavier' African plate to the 'lighter' Pacific Basin hemisphere since the Jurassic period, has resulted in some unexpected findings and conclusions. Using the above mathematical model with offset COM, it has been possible to

(i) demonstrate that the major forces driving tectonic plate movements are directly related to the rotational velocity of the planet Earth,

(ii) develop an equation to quantify the Differential Circumferential Tensile Stress Forces (DCTSF) in the Earth's rim responsible for the breaking-up of a supercontinent,

(iii) introduce the concept of Momentum gained by the moving detached tectonic plates and define its role as the major force driving subduction,

(iv) separate the study of tectonic movements from the study of subduction processes,

(v) demonstrate that convection currents and extrusion of magma onto the ocean floor are modified by tectonic plate movements and establish that

(vi) the forces described in this treatise allow for an alternative 'Cycle of Planet Regeneration', different from the presently accepted Wilson Cycle, which is based on heated convection currents, to be proposed.

The following terms and their acronyms were introduced into the geological vocabulary: 'Differential Circumferential Tensile Stress Forces '(DCTSF), Momentum, 'Sea floor Stretching ', 'Radius of Eccentricity', 'Gravitational Crank Coupling; (GCC) and 'Cycle of Continuous Lithosphere Regeneration' (CCLR).

6. Equations Relating Circumferential Stress Forces to the Offset Centre of Mass

6.1 Introduction

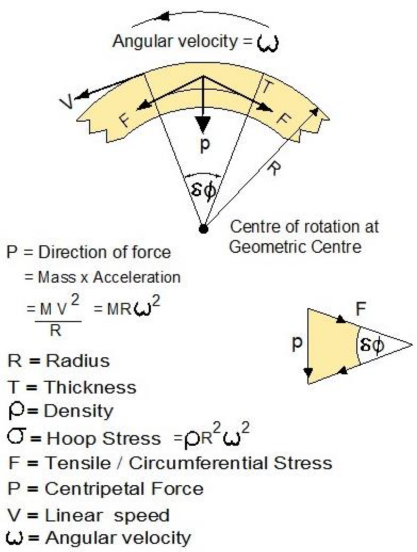
As pointed out earlier, the literature survey has shown that the incorrectly but so called ‘inertial forces’ associated with the rotational velocity of the Planet Earth have been almost totally dismissed as being a viable force to sustain tectonic processes. This is surprising since Kepler’s laws of planetary motion clearly demonstrates the Sun’s gravitational control over both the orbital and rotational movements of the planets. As it is impossible to rotate a body about its dimensionless centreline (see Section 5) an offset torque force is required to allow the Sun to control planetary movements..

This treatise postulates 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 (Sections 3, 4 & 5). The unbalance arises from the asymmetrical weight distribution within the rotating body. This in turn causes the circumferential tensile forces 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 Rift Valley appears to be in tension.

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.

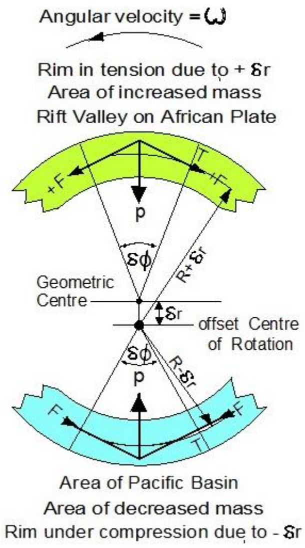
6.2 Model 1: Rigid body dynamics

The simplest model is to consider the Earth as an eccentrically rotating solid body such as unbalanced flywheel. Although this model (Figs 18a &18a and Appendix 3) accounts for the compressive and tensile stresses developed in the outer rim, it does not describe the circumferential forces which are thought to be linked to the tectonic forces resulting in plate movement.



Centripetal Force Diagram
Tensile force in Outer Rim

Fig 18a



Differential Circumferential
Tensile Stress Diagram

Fig 18b

As stated in the mathematical analysis below, 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 is based on having relative movement between the outer rim or crust and the main body or mantle. In Fig 19, 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 (<0.25 km) of the COM the models will be interchangeable.

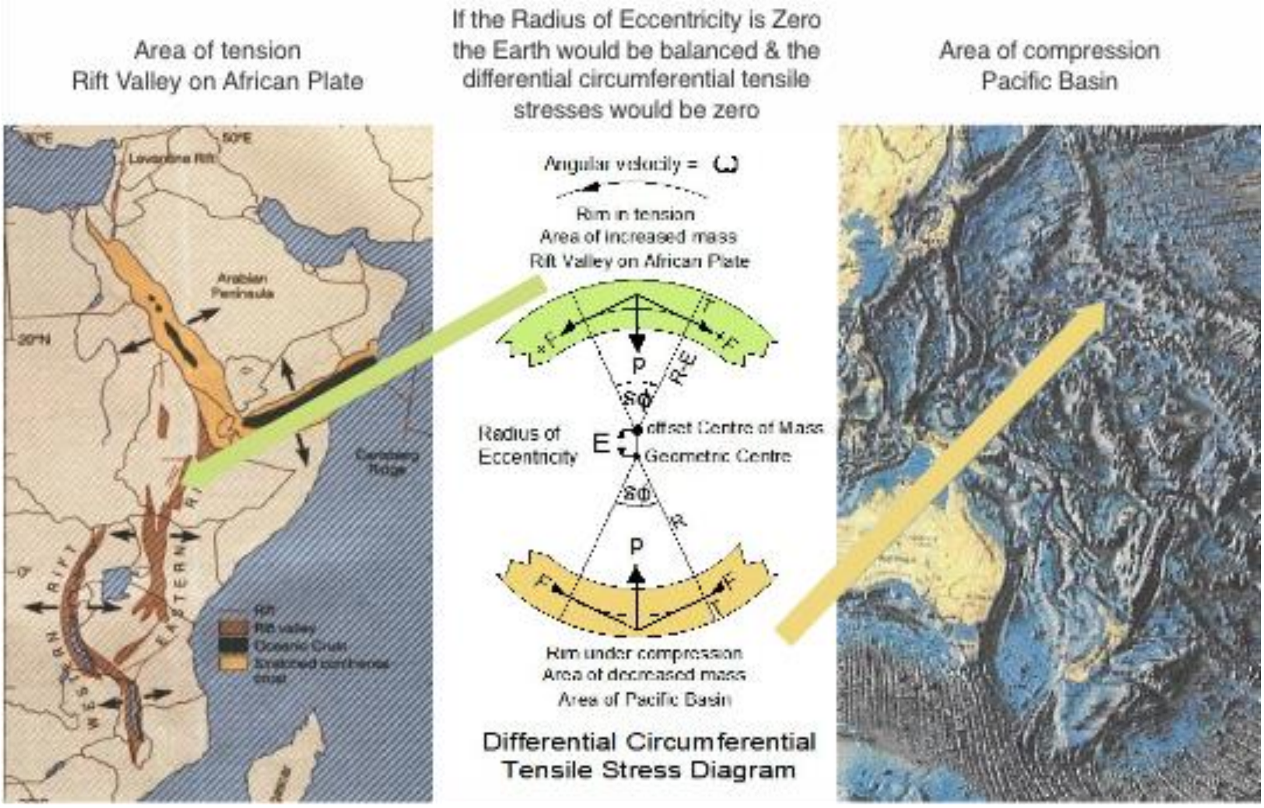


Fig 19: Areas of tension and compression in relation to the differential circumferential tensile stress diagram.

6.2. Mathematical analysis of Model 1

This analysis (see Appendix 5) 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 metre
T = Thickness	1.0×10^3 metre
ρ = Density (kgm^{-3});	2.8×10^3 kg m^{-3}
ω = Angular velocity (radsec^{-1});	7.27×10^{-5} rad s^{-1}
σ = Hoop Stress (N m^{-2})	

Consider a cylinder of mean radius R and thickness T rotating at an angular velocity ω about its axis (Fig.18a):

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

The radial force on the element = mass x acceleration = $(\rho R\,\delta\theta.T)\,R\,\omega^2$

This will produce the Hoop Stress σ

Resolving radially

$2\sigma t \sin\frac{1}{2}\delta\theta = \rho R^2 \omega^2.T\,\delta\theta$ (as $\sin\frac{1}{2}\theta \rightarrow \frac{1}{2}\theta$)

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

If the centre of rotation is displaced δr, from the centre of mass (Fig 18b) then the tensile force on the 'heavier side' will be increased by the following amount:

Thus, 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 values stated above:

The additional tensile stress

$= 2.5 \times 10^3 \times (7.27 \times 10^{-5})^2 \times (2 \times 10^3 \times 6.4 \times 10^6 + 10^6)$

$= 1.89 \times 10^5$ N m^{-2}

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

Thus 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, tensile stress will have a negative value

The tensile stress is thus = -1.89×10^5 N m^{-2}

This negative tensile stress is the compression stress = 1.89×10^5 N m^{-2}

6.3 Model 2: Outer rim able to slide relative to main body

The mathematical analysis is based on the concept of the outer rim being allowed to slide relative to the main rotating body (Fig 20a and Fig 20b).

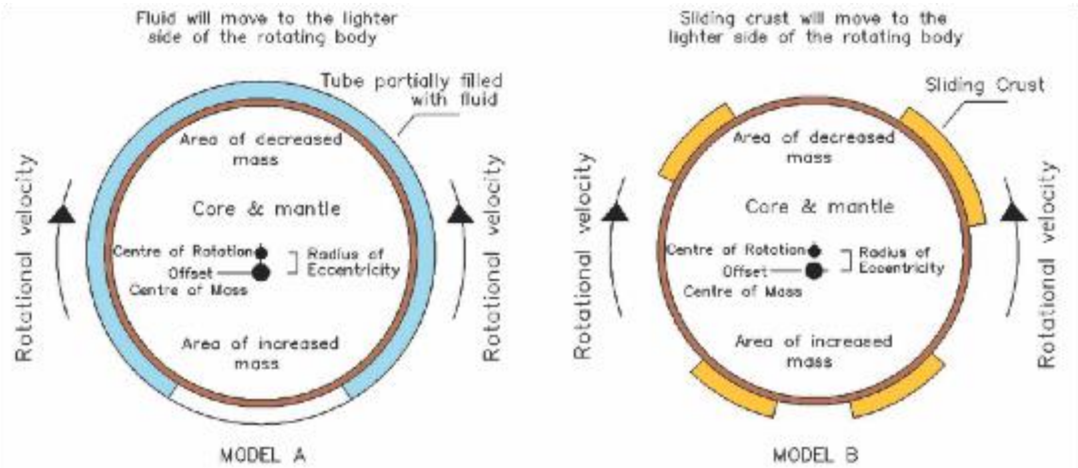


Fig 20a & b, Models A and B used for the calculation of the differential circumferential stress forces required to move the crust at the crust – mantle interface

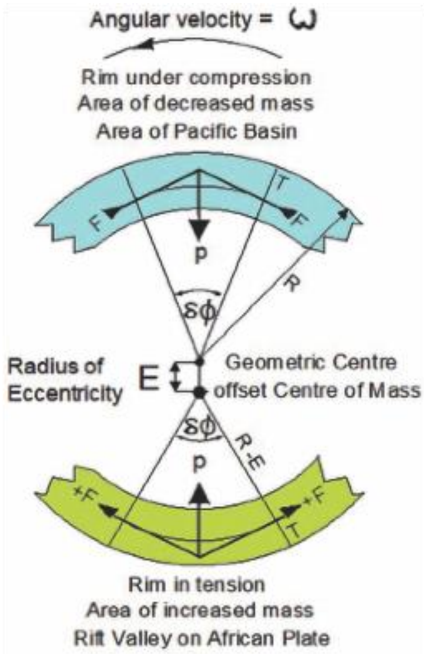


Fig 20c Circumferential tensile stress diagram for sliding crust model

To determine the forces postulated as being responsible for tectonic movement, the model used is one in which the thin crust can slide relative to the solid body at the crust/mantle interface. By way of illustration Fig 20a 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[37] than that of the Atlantic and Indian Oceans. This situation is noted by the difference in tidal heights either side of Panama.

The mean level of the tidal heights is also affected by weather patterns, salinity and possibly Coriolis forces. Fig 20b shows the analogous situation in which the thin crust in made to slide from the ‘heavier’ side to the ‘lighter’ side. As the mass of the crust in negligible when compared to the bulk planet, its distribution will have zero effect on both the moment of inertia and the position of the COM of the Earth.

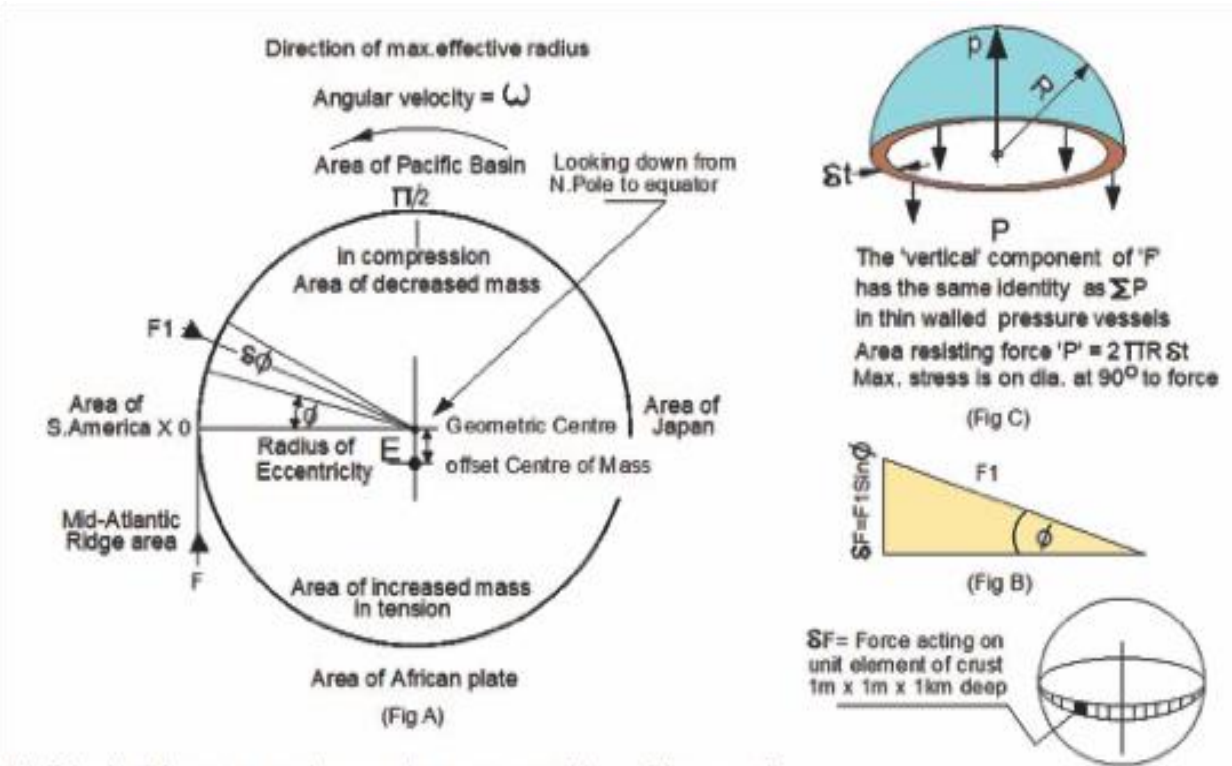
Fig 20c shows the vector diagram with the offset COM used to quantify the forces associated with a sliding crust.

If we consider the crust as being able to move relative to the mantle, albeit it over a long geological time span, then a simple force diagram (Figs 21a & 21b) can be constructed by making the following assumptions:

i. The crust is a thin shell that can slide relative to the mantle.

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.



(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 max. effective radius

(C) Analogous derivation of the 'vertical' component in a thin shell sphere under pressure (P)

Fig 21a, b & c

By approaching the problem in terms of a thin shell moving relative to the mantle, it is possible to consider what 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 surface of the Earth due to the centre of mass (COM) being offset from the principal axis of rotation, the term 'radius of eccentricity' was introduced to denote the distance between the centre of mass and the major axis of rotation. In doing so the following relationship was derived:

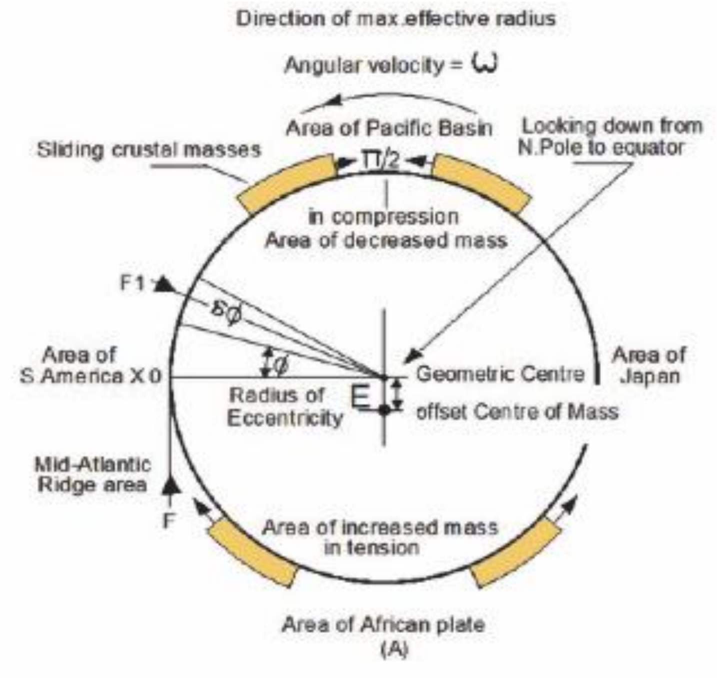
Total circumferential force (F) acting on the crust = M R $\boldsymbol{\omega}^2$ E π/4 - see Equation (2) below.

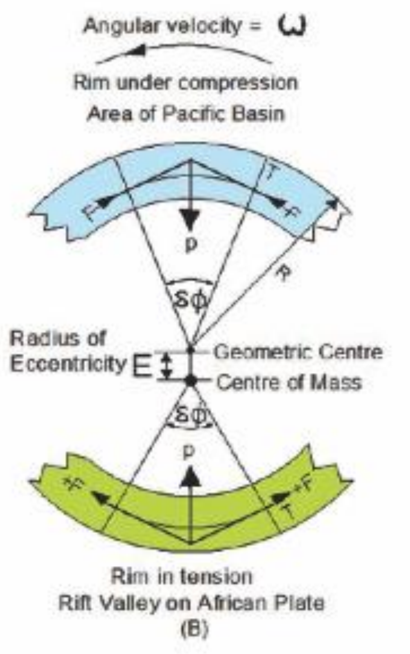
The magnitude of the derived circumferential stress (F) is thus dependent on the distance between the geometric centre and the centre of mass, i.e. (E) the 'radius of eccentricity'. In a limiting case, if the 'radius of eccentricity' is zero, the rotating body will be balanced, and the centripetal forces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

Consider a thin shell cut across the Earth's diameter at the Mid-Atlantic Ridge (Fig 21a, b & c). The force tending to cause 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[7]. Figure C in Fig 21 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 21b shows the force and vector diagrams used to determine the magnitude of the circumferential stress in the direction of the maximum effective radius. For ease of understanding the force diagram is superimposed on the major geological features on the equatorial belt.

Figs 22 & 23 show both versions of the vector drawing describing the mass imbalance due to the offset COM.





Alternative methods of showing the principal forces superimposed across a section of the equator

Fig 22 *Fig 23*

The mathematical analysis here is repeated in Appendix 3 as a separate entity.

Notation			Value
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 s^{-1}
	=	Angle. (rad)	
δe	=	Effective eccentricity at angle θ	
F	=	Total force at point X (N) (cf. Fig.11)	
F_1	=	Radial force due to eccentricity at θ	

Then from the 'force vector diagram' at surface at an angle θ:

Vertical component of F_1	δf	=	$F_1 \sin\theta$
Effective eccentricity at angle Θ	δe	=	$E \sin\theta$
And mass of segment	$R\,\delta\theta$	=	$M R\,\delta\theta$.

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

$= M R\,\omega^2 E \sin\theta\,\delta\theta.$

The vertical force component $\delta f = F_1 \sin\theta$

$= M R.\omega^2 E \sin\theta \sin\theta\,\delta\theta$

$= \mathbf{M R \omega^2 E \sin^2\theta\,\delta\theta}$ **Equation 1**

Thus, the total vertical force

$$F = \int_0^{\pi/2} M R\,\omega^2 E \sin^2\theta\,d\theta$$

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

$$= M R\,\omega^2 E\,(\pi/4 - ¼.0) - (½.0 - ¼.0)$$

Total vertical force (F) = $\mathbf{M R \omega^2 E \pi/4.}$ **Equation 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 kg m^{-3}, then for a column of crust of section 1 metre x 1 metre

The mass per unit area of crust = $1{,}000 \times 1 \times 1 \times 2.8 \times 10^3$ kg

$= 2.8 \times 10^6$ kg

The radius of the Earth (r) = 6,400 km

The angular velocity of the Earth[55] at the equator (ω) = 7.27×10^{-5} rad s^{-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 = 7.44×10^{-2} N m^{-2}, 0.744 Bar or c. 10.7 lbs.in^{-2}

6.4 Alternative analysis approach to the above

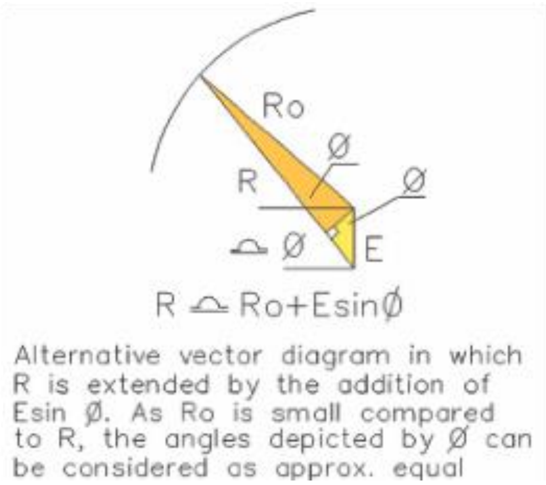


Fig 24

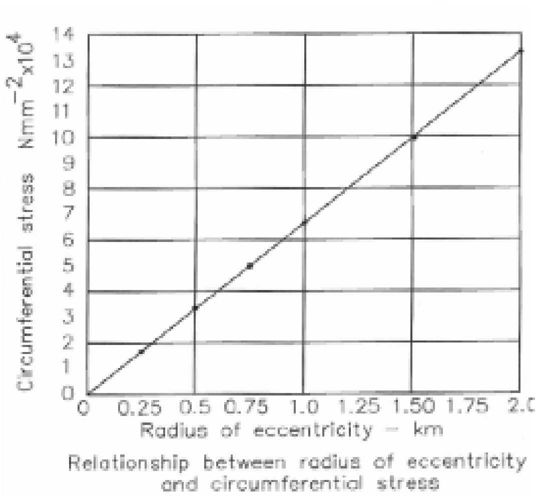


Fig 25

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. 24 is used for this analysis. Fig 25 shows the relationship between the Radius of Eccentricity and the circumferential stresses. Fig 24 shows the relationship between F, E and μ.

The mass of the segment R δθ = M R δθ

the radial force F_1 = Mass R ω^2

$$= (M R \delta\theta). R. \omega^2 = M \omega^2 R^2 \delta\theta. \text{ thus}$$

$$\delta f = M \omega^2 R^2 \sin\theta\delta\theta.$$

With reference to Fig. 24:

$R = R_0 + E\sin\theta$. thus,

$\delta f = M \omega^2 (R_0 + E\sin\theta)^2 \sin\theta \, \delta\theta$ which approximates to

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

$= M \omega^2 (R_0^2 + 2E R_0 \sin\theta) \sin\theta \, \delta\theta.$

Thus, the increase of

$$\delta f = \delta f - M\,\omega^2 R_o^2 \sin\theta\,\delta\theta$$

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

$$= M\,\omega^2 \sin\theta\,\delta\theta\,(R_o^2 + 2E\,R_o \sin\theta - R_o^2)$$

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

$$= \mathbf{MR_0\,\omega^2\,2\,E\sin^2\theta\,\delta\theta} \qquad \textbf{Equation 3}$$

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 diagrams (Figs 19 and 21) is considered valid for determining Equation 2 by integrating between 0 and π/2.

6.5. 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. This is shown pictorially in Fig 26.

Fig 26 Circumferential stress applied to a vehicle

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 1,000 mm x 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 pushed by 118 people each of whom weighs 180 pounds (81.8 kg) (see Fig 22).

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 about. 1:200. 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 in lb in^{-2}) 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 m^{-2} (0.2 psig) acting on the large surface area of a ship's sail will cause the ship to move across water.

6.6 Coefficient of Friction

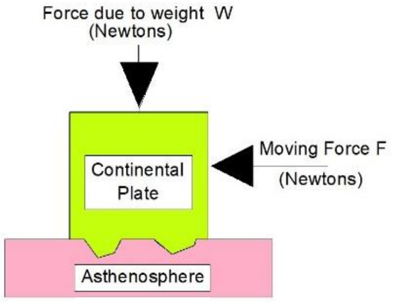


Fig 27

The estimation of the magnitude of the circumferential forces acting on an element of crust (see Section 6.2 and Appendix 3) allows the calculation of the coefficient of friction (μ) at the crust / mantle interface. The force diagram required for this calculation is depicted in Fig 27. The determination of the coefficient of friction will thus yield an indication of the material and topography at the crust/mantle interface.

Let F be the 'moving force' on the 1 m x 1 m x 1,000m crustal column and W = the 'vertical downward force' exerted by the weight of that column.

If we take the radius of eccentricity to be 1 km, then from equation 2 as above we have

F = 6.64×10^7 N and

W = $2.8 \times 10^6 \times 9.807$ kg

N = 2.745×10^7 N.

Hence

μ = F / W = $6.64 \times 10^7 / 2.745 \times 10^7$ = 2.419.

Alternatively, if the radius of eccentricity is taken to be 0.5 km then

μ = 1.35

The graphical relationship between μ (coefficient of friction) and the calculated force (F) and the corresponding radius of eccentricity is shown in Appendix 3.

The research programme by Morrow and Lockner[32] on the cored rock samples from the Hayward Fault region in Northern California showed the coefficients of friction of these samples (sandstone, basalt, gabbro and keratophyre). These were calculated from the fracture angles which occurred under the applied axial loading and were shown to range between 0.5 and 0.9. At low applied loads of 32 and 64 MPa (to simulate depths of 2 and 4 km) the μ values for the gabbro, basalt and keratophyre varied between 1.0 and 1.5. The calculated values of the coefficient of friction are not unrealistic and compare favourably with laboratory simulations.

7. Centripetal Forces and the Birth of Plate Tectonics

7.1 Birth of Tectonics

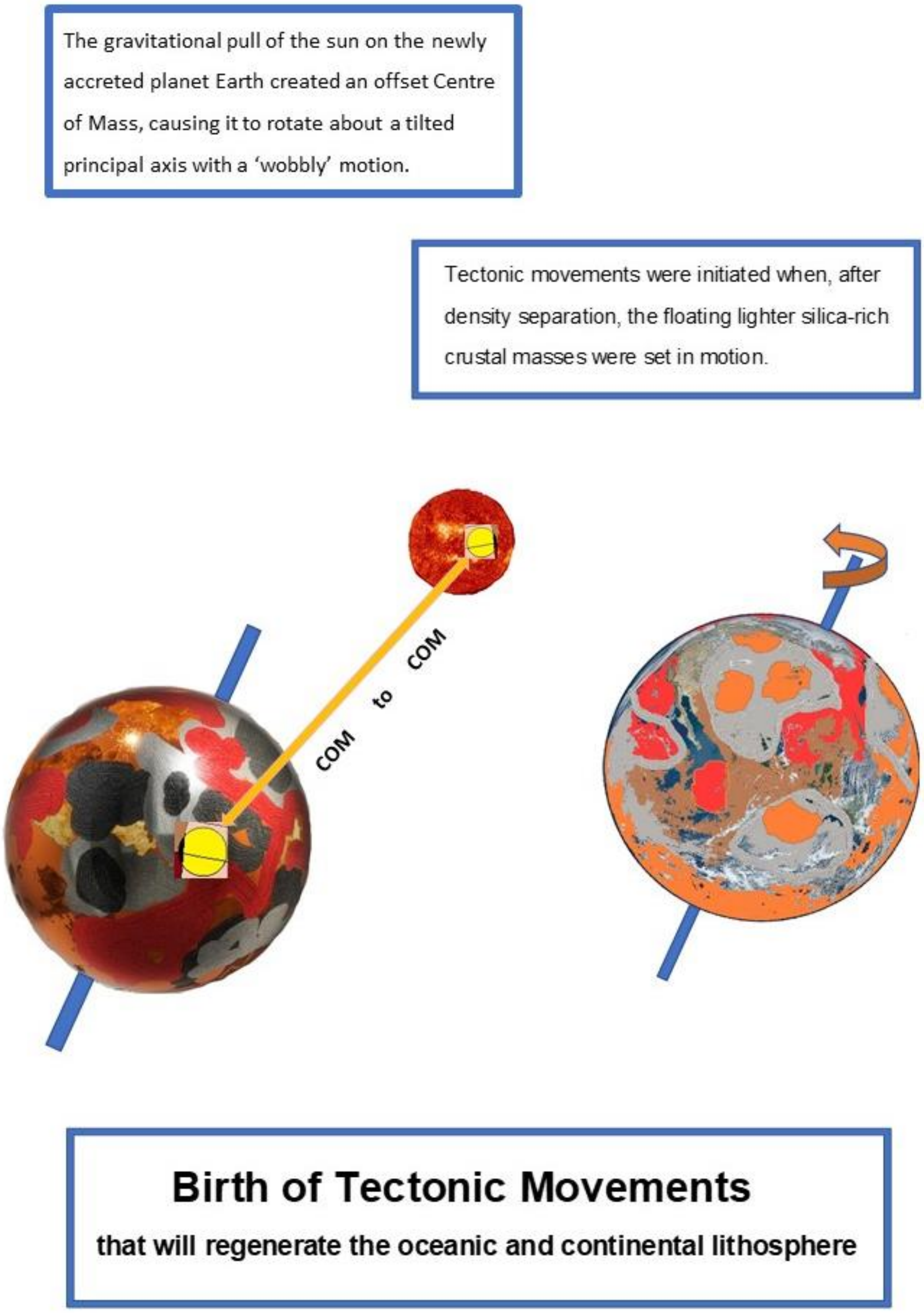


Fig 28 Birth of Tectonics

Fig 28 illustrates a scenario for the birth of tectonics, on which current thinking is speculative. Notwithstanding that, there must be a factor or force common to the planets in the Solar System as, apart from Venus and Uranus, they have broadly a similarly inclined axis of rotation and a broadly similar axial rotation period (apart from Venus and Mercury).

Therefore, it is postulated that, after accretion from the dust clouds swirling around the Sun, new planetary bodies would have gained momentum owing to their mass and orbital velocity. The inward gravitational pull of the more massive Sun prevents them from escaping from their orbits. This is similar in concept to the inward pulling centripetal forces associated with an orbiting mass fixed to the end of a tether.

A mutual gravitational pull will exist between the centre of mass (COM) of the Sun and that of the newly accreted planet. For planetary rotation on its own axis to be initiated, the planet's COM must be pulled off-centre to provide leverage for a torque force.
This action of pulling the COM off-centre will cause the planet to tilt towards the heavier side. Under these circumstances, the planet will behave like an unbalanced rotating body with tensile and compressive forces around the rim.

After the separating out of differing density planetary materials as these molten materials cool, lighter silica-rich materials will form crustal masses floating on the denser mafic mantle and metallic core material. It is postulated that this mobile outer layer will swirl around the surface soon after the beginning of planetary formation. It is this action that will initiate the continuous tectonic processes that will continuously regenerate the lithosphere.

7.2 The effect of centripetal forces on plate movements

Consideration of the calculations in Appendix 4 shows that the Centripetal, often referred in literature as the Radial Outward Force, F= M$\boldsymbol{\omega}^2$R (in Newtons), is responsible for the equatorial bulge that causes a 0.34% reduction in the gravitational force from that experienced at the poles where the rotational velocity is zero. This difference is considered enough to cause the plates to move around the Earth on a frictionless surface.

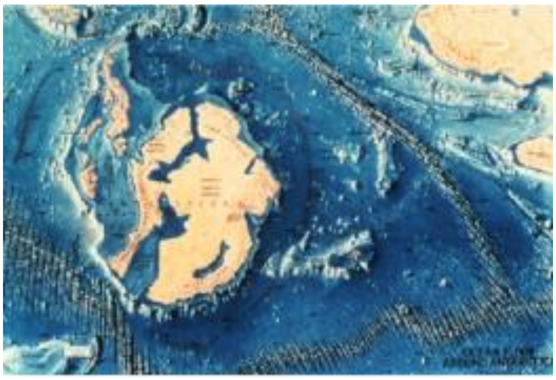
At this juncture it is pertinent to note that, due to the low rotational velocity of Venus at the equator (one rotation in 243 Earth days = 6.5 km h^{-1}) compared with 1,674.5 km h^{-1} on Earth, the centripetal forces available compared to the similar-sized planet Earth will be in the ratio of (6.5)^2 / (1,674.5)^2 = 42.25 / 2,803,950.25 = 0.000015:1. This would give a stress value of 3.9 x 10^{-3} Nm^{-2} (0.059 psig). The circumferential forces thus available for tectonic activity on Venus are extremely small.

The calculations derived in Appendix 4 are mainly applicable to the longitudinal east and west movements of the plates away from the African plate and at first sight do not really help explain the northwards movement and breakup of Pangea from the Permian to the present. A demonstration rig (Fig 29) was made using a hemispherical bowl with four vertical slots in which different sized metal bolts are free to move along and within the slots.

Fig 29

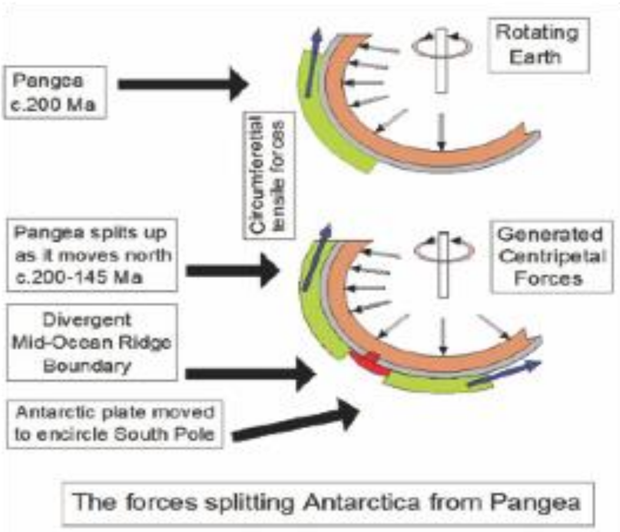
On rotating the bowl, the bolts travelled upwards and outwards. This centripetal force action mimicked the northward movement of Pangea and the associated upwards separation of the South American plate as it moved westwards and the Indian and Australian plates as they moved eastwards. The possibility that the above process is responsible for the creation of the divergent southern circumferential East Pacific and Antarctic ridges and the south-west and south-east Indian ridge boundaries is a matter for consideration.

Furthermore, it is also feasible that the same centripetal forces are simultaneously pushing the Antarctic plate southwards to move into a larger area around the south pole. The centripetal forces creating the oblate shape of the Earth will also tend to move or pivot the northern land masses comprising the Eurasian and North American plates in a southerly direction into a larger diameter area.



These processes will result in putting the Pacific Basin under compression. Fig 30 is a National Geographic map[49] of the Mid-Ocean East Pacific and Antarctic ridges including the south-west and east Indian ridge boundaries with perpendicular fracture zones.

Fig 30



The pictorial 'force' diagram shown in Fig 31 yields a viable explanation how west-east centripetal or radial forces can result in the south-north plate separation.

Fig 31

7.1 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 as used in Appendix 2

ρ = Average density of the crust 2.8×10^3 kg m^{-3}

M = Mass of 1m^3 of element of crust 2.8×10^3 kg

R = Radius of Earth (m): 6.4×10^6 metres

ω = Angular velocity (rad s^{-1}): 7.27×10^{-5} rad s^{-1}

Thus

Fr = Radial Outward Force (N)

= $M \omega^2 R$

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

= 94.71 N

= c 9.65 kgf

Thus, for every 1 tonne of crust, the outward force at the Equator due 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 crustal plates to move around the Earth's surface on a frictionless mantle.

8. Circumferential Forces and Plate Movement Considerations

This section examines an example where consideration of the differential circumferential tensile forces (DCTF) in the Earth's rim allows alternative plausible explanations of the observed movements of the continental plates (CP) and the oceanic lithosphere (OL).

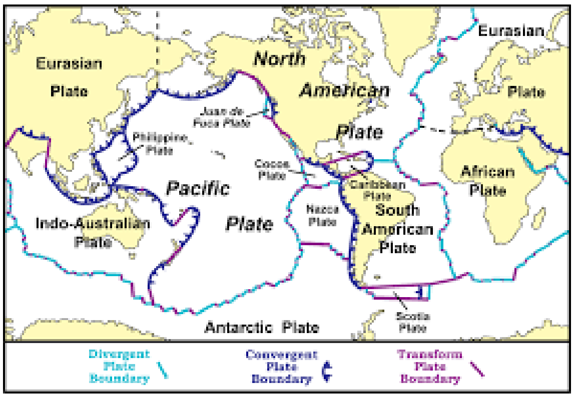


Fig 32a

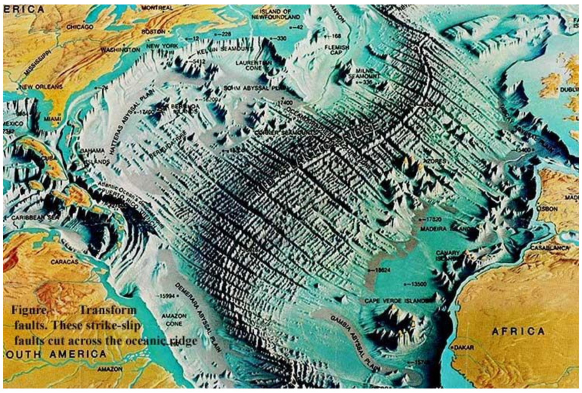


Fig 32b

Fig. 32 c
Position 1 Indian CP joined to Eurasia
Position 2 Eurasia moving into Pacific Basin

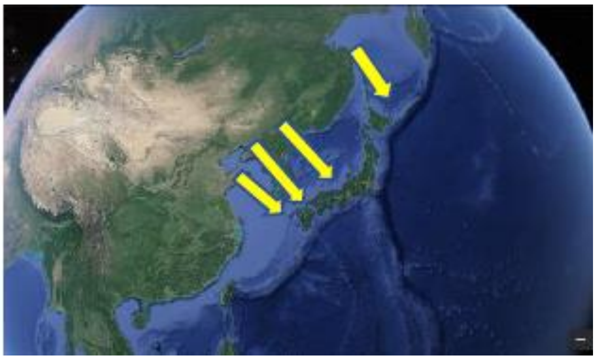


Fig.32 d
The Japanese and Philippine arcs began to separate from Eurasia c.20 Ma after collision with the Indian Plate

8.1 Transform Faults in the Mid Atlantic Ridge (MAR)

The transform faults as noted on the world map (Fig 32a) and the detailed MAR as depicted on the enhanced photographed NOAA map (Fig 32b) may not necessarily be attributed in every case to a simple displacement of parts of the ridge either side of the main ridge line by the lateral movements of the plates after separation. The initial northward pivoting split of Laurasia from Pangea (190 Ma) and the subsequent break up into the North American and Eurasian plates from the larger Laurasia plate (180 Ma) would have initially only stretched the mantle between them. By 130 Ma oceanic crust was formed between Southern Africa and South America. By 120 Ma a narrow sea was in place between Southern Africa and South America. Separation of South America and Africa progressed from south to north. At this stage NW Africa was still joined to Brazil. The equatorial segment of the Atlantic opened c.110 Ma.

Visual examination of the direction of the displaced ridge and fracture lines that occurred c.110 Ma ago suggest a pivotal motion of the South American plate. As the separation of the two plates started in the south and the movements were over a spherical surface, this is not altogether unexpected. The curved shape of the Puerto Rican trench, Cuba, the Dominican Republic, and the Barbados Island chain are also indicative of a pivoting action by South America as it separated from North Africa.

The possibility that the whole area was heated by volcanic activity as seen by the presence of the Cape Verde islands, the Canary Islands stretching northwards towards Madeira and the Azores may have resulted in the lowering of the ductility of the basically younger mantle in the vicinity. This would have allowed for extra stretching before breakage. This situation is typical of what happens when a ductile test piece is subjected to a mechanical tensile test in a laboratory. Under these circumstances the transform fault may be seen as a 'delayed' fracture.

1. The continental mass of Pangea would have been shifted northward by the circumferential tensile forces (CTF)

2. The ductile mantle would have stretched under these applied tensile stress forces.

3. The stretching would have thinned the mantle and the pulling action would be noted by the elongated stress lines some of which may have developed into 'Fracture Zones'. The length and width of these 'Fracture Lines or Zones' would have been subject to varied mantle composition and the latitude related rotational velocity-based stress forces.

4. Finally, fracturing at right angles to the stress forces would have occurred with the subsequent creation of separate plates. At this point magma would intrude into the widening ridge giving rise to the mirror imaged parallel lines of paleo-magnetic reversal cycles either side of it.

5. Although the 'Fracture Zone' stretching would cease, some stretching will continue especially in the areas where the upper mantle is relatively more ductile. The increased ductility could well be a function of the temperature in the upper mantle

6. The displaced 'Transform Fault' along the Mid-Atlantic Ridge, starting at Greenland and continuing through to a line drawn between North Africa (Morocco) and the top western point of Brazil in South America, may well have occurred during the initial breakaway stage of the North American plate prior to the later separation between the South American plate and the central and southern part of the African plate.

7. Once further separation had taken place between the northern part of the African plate and the Eurasian part of Laurasia, ingress of water from the Panthalassa and Tethys Oceans allowed the beginning of the formation of the new Atlantic, Indian and Pacific Ocean boundaries (at this stage, at c.150 Ma, the North Atlantic was yet to open).

An attempt has been made to display the above sequence in the 'Sea floor Stretching' illustration Fig 35, section 12.3.

9 Introduction of ‘Seafloor Stretching’ to Replace ‘Seafloor Spreading’

The introduction of the CTF into the outer rim of the Earth has major implications regarding the opening and the formation of oceans. The application of the circumferential force to the eastern side of the South American plate will cause it to be pushed away from the rest of Pangea. This will widen the Mid-Atlantic Ridge (MAR) and allow the passive ingress of magma on the sea floor.

It is interesting to note that at present the MAR has moved about half the distance moved by the South American plate. As postulated in Section 6, this separation will continue until the crustal plates are moved to the lighter (Pacific Basin) side or hemisphere of the Earth. The intrusion of magma onto the separating ocean floor boundaries which is generally credited with the force capable of moving continents apart causing ‘sea floor spreading is now seen as being an inevitable passive consequence of the mantle being split by the circumferential stresses. This process is referred to as ‘sea floor stretching’ in this treatise. The absence of severe distortion at right angles to the moving force is a major indication that compression of the extruded magma and thus the oceanic lithosphere did not take place.

10 Consideration of Tectonic Plate Movements by Circumferential Forces

Following on from the initial break-up of Pangea, the separated continental blocks, presently postulated as being driven by CTF will move towards the lighter side of the planet. If these movements away from the now centrally positioned African plate are approached from a convection current circulatory system as the cause, it would be difficult to reconcile all the following plate units moving towards the Pacific Basin:

(1) Pangea moving north in the Permian

(2) what is now the Eurasian plate moving north-east and rotating

(3) the South and North American plates moving west and

(4) the Indian and Australian plates moving north-east.

The same difficulty would apply in reconciling these plate movements with

(a) the apparent north-westward movement of the Pacific plate over the Hawaiian hot spot in forming the Hawaiian-Emperor volcanic seamount chain

(b) the convergent boundary along the Aleutian Trench

(c) the divergent boundary of the east-west circumferential Pacific/Antarctic Ocean ridge and those extending south-east and south-west from India.

Fig 32a shows the present plate movements and their different type boundaries. It is extremely difficult to offer a rational explanation to cover the various circulatory convection motions particularly as they would have to consider the different Earth circumference measurements with latitude.

If, however, the various movements within the Pacific Basin are considered using CTF the following explanations may well be considered viable:

1. The Eurasian continental plate, despite the impediment to its westward motion by its engagement with the Indo-Australian plate at the Himalayan interface, is being subjected to a Euler pivotal action over the Pacific oceanic crust in a westward direction.
2. The North American plate including the transform fault area shows an overall trend for an eastward pivotal movement over the Pacific Basin as noted by the convergent boundary at the Juan de Fuca and the Cocos plate areas.
3. The inward and downward pivoting motion of both the Eurasian and North American plates, coupled with the centripetal force causing the total land mass to move southwards to occupy a larger area at a lower latitude, could well have contributed to an east-west compression-initiated trench split between them in the Aleutian area.
4. To the above, it is possible that a S-N compression component is applied by the north-north-west movement of the Indo-Australia plate on the western side of the Pacific Basin. At present the anticlockwise rotating Australian plate is moving eastwards towards the Pacific basin. This additional compressive force may have contributed to what appears to be a distorted trench rich Pacific Basin area between the Eurasian plate and the Emperor Seamount-Hawaiian Island chains extending south to the Kermadec trench.
5. The collision of the Indian plate with the Eurasian plate would have weakened the suture lines between the various CP's that amalgamated to form Pangea. These CPs were fragments of the previous supercontinent Rodinia, which began to break up c. 750 Ma. The India-Eurasia collision is credited with the rifting of the Japanese and Philippine peninsulas into the Pacific Basin from the main Eurasian CP at c. 20 Ma. At the same time, the Lake Baikal rift in Siberia also opened, along with, it must be assumed, the

numerous other N-S rifts across the Eurasian CP. These intracontinental rifts required an applied force to physically separate the continental blocks either side of them. The high-magnitude DCT forces that this treatise postulates are considered responsible for the break-up of a supercontinent such as Pangea (and presently seen splitting the African CP at the Rift Valley) and are far more likely to have been responsible for exploiting the weakened suture lines than heated convection currents beneath the CP. The eastward movement of the Japanese Arc and the Eurasian plate over the OL as opposed to being subducted by density differences is discussed in items 6 and 7 below.

6. It can be argued that the CTFs are splitting up the Eurasian plate at its eastern margins while at the same time pushing Eurasia eastwards into the Pacific basin. This would account for the opening of the Japanese and China Seas by the relatively faster movements of the peninsulas from the mainland. This implies a two-speed action which is possible if the CP moves over the OL. It is extremely unlikely to have a two-speed subduction process on the same slab of lithosphere. This would be noted in the topography of the CP as the OL would be laterally distorted as is the very possible situation in the Andes Mountain range.

7. Field observations of the faults in the Pacific Ocean east of Japan (Prof. S. Suzuki personal communication) do indicate that the Eurasian plate is moving over the Pacific plate as distinct from being pulled by subduction forces (Figs 32c & 32d).

8. As discussed in item 5, it is conceivable that the DCT forces credited in this treatise as causing the break-up of Pangea are also responsible for the numerous intracontinental N-S rifts (notably the Lake Baikal rift) on the Eurasian plate.

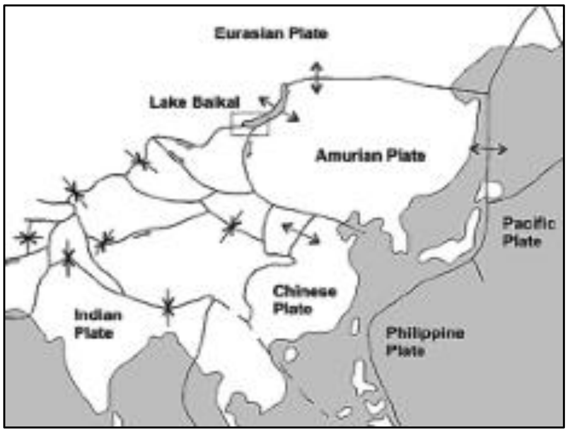


Fig 33: Location of Lake Baikal

9. The obvious ovality of both the Japanese and Philippine arcs is of interest. The ovoid shape may well be due to the combination of the centripetal forces acting against the hoop stress of the outer lithosphere by stretching it to fit into a larger latitude band area and the circumferential forces causing the east-west break away movement of the peninsulas. It is not inconceivable that the circumferential tensile forces will act in opposition to the centripetal forces on the Eurasian plate side and synergistically on the Pacific Basin side.

10. It is also possible that the east-west circumferentially aligned Pacific-Antarctic together with the south-east and south-west aligned divergent boundaries are a result of the centripetal forces moving a major part of Gondwanaland northward whilst at the same time centralising the southern Antarctic plate to find the largest area around the South Pole. This scenario would give a plausible explanation for the situation as shown in Fig 31 (Section 7) and detailed in this section. It is difficult to explain the disposition of the boundaries at the polar region using the concept of convection current considerations

11. The above scenarios are in keeping with the projected behaviour as outlined in Fig 19b in which the heavier side, split under tension, is opposite the lighter side in compression, 180 degrees away on the other side of the planet.

11. Introduction to the Momentum of a Moving Tectonic Plate

11.1 Explanatory notes, and key to acronyms and general colour coding for Section 12

To convert the stress factors of the principal forces into Newtons they need to be multiplied by the area of the segment of area (Au) over which they are applied. Au is used as a general term for the area over which a particular force is applied. Where possible Au is taken as a 1000 km x 1m segment cut through the continental crust and oceanic lithosphere.

AS	=	Asthenosphere $\rho = 3.7 \times 10^3$ kg m^{-3}
Acp	=	X-Sectional area of CP
Au	=	General term for area of segment (see notes above)
Aw	=	Accretionary wedge (or prism, some authors)
Mantle	=	$\rho = 3.7 \times 10^3$ kg.m^3
OL	=	Oceanic Lithosphere, $\rho = 3.3 \times 10^3$ kg m^3
OC	=	Oceanic crust
CP	=	Continental plate, $\rho = 2.7 \times 10^3$ kg m^3
Mcp	=	Mass of CP
Wcp	=	Weight of CP
Fwcp	=	Force owing to weight of CP
Vcp	=	Velocity of CP
p	=	Momentum of CP = Mcp * Vcp
Fbs	=	Bending stress of OL
Fby	=	Buoyancy force
Fcir	=	$M\ r\ \omega^2\ E\ \pi/4$ = Circumferential tensile stress.
Fie	=	Isostatic equilibrium
Frv	=	Force due to Friction & Viscosity
Fwslab	=	Force owing to weight of slab
Fsp	=	Force due to slab-pull
Frp	=	Ridge-push force
MOR	=	Mid-Ocean ridge
MORB	=	Mid-Ocean ridge basalt
N	=	Newtons
SM	=	Spreading magma

The general formulae are written as follows:

Supercontinent breakup	=	Fcir * Au or Fcir * Acp if applied to an actual continental plate
Tectonic plate driving force (N)	=	Fcir * Au followed by Momentum = Mcp * Vcp
Subduction driving forces (N)	=	Fsp * Au + Fwcp * Au.
Resistive Forces (N)	=	Frv * Au + Fby * Au + Fbs * A

* Symbol used here as multiplier for clarity

Grey	=	Oceanic crust
Yellow	=	Oceanic rigid upper mantle
Pink	=	Asthenosphere (ductile upper mantle)
Orange	=	Lower mantle
Brown	=	Accretionary wedge

11.2 Generation of momentum of a moving tectonic plate

It was the inability to understand how a thermal current ‘somewhere’ (Section 3) in the mantle can drag the Nazca plate under the South American plate with sufficient force to lift its western boundary c.5 km above sea level, and in doing so create the mighty 7,000 km long by 200-700 km wide Andes mountain range, that prompted this study. It is surprising that the general explanation given in the literature survey and textbooks including geological teaching pamphlets[22A], is that this massive orogenic process was simply created ‘by subduction’ and thus by implication the Hess model.

The development of equations (Section 6), 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. 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 upper mantle (asthenosphere), and in doing so, initiate the subduction process that will finally force the OL into the lower heated mantle. Under these circumstances, subduction is seen 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 via its subduction under a CP.

The process of subduction is attributed to the difference in density between the heavier OL and lighter CP. The introduction of gained momentum **(p = Mcp x 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, roll back or by partial melting in the asthenosphere, and with it the loss of the slab-pull force, has 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 pictorially that the forces 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 heavier CP over the OL initiates the subduction processes.

11.3 The role of momentum at convergent boundaries

Having introduced the concept of momentum to a moving CP immediately allows for a re-evaluation of the OL-to-OL collision sequences prior to the CP-to-CP collision at convergent boundaries. At present the formation and distortion of an accretionary wedge is generally attributed to 'subduction' and 'slab-pull'. An example is the complexity of the geological processes in the Nankai Trough[28A] (which includes the orogenesis in central Japan) which are related to slab-pull and the westward subduction of the Philippine Sea plate that formed the Ryukyu and Philippine trenches.

In contradiction, the observations of the opening of the Sea of Japan by Professor Shigeyuki Suzuki (personal communication) plus illustrations commenting on the mathematical analysis of the circumferential forces (Section 6) by the author suggests that the Eurasian plate is moving over the oceanic lithosphere towards the Pacific. While this argument in no way detracts from the veracity of the experimental work carried out by Kimura[28A], the same results would be obtained by converting the driving forces distorting the accretionary wedge from pull by subduction to push by circumferential forces.

Despite its low velocity, the Eurasian continent 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 eastern edge of the Eurasian plate.

Furthermore, using this approach, viable explanations can be offered to explain the initial OL-to-OL at the start of a CP-to-CP collision sequence. The most notable CP to CP collision is 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. This matter is dealt with in detail in Section 12.9.1. Fig 41 shows a typical obduction sequence where ocean crust has been pushed upwards onto the opposing continental plate instead of being subducted. This scenario would be easier to understand if it is considered as a head-on vehicle crash in which the collision forces embrace a velocity factor.

Similar considerations must also be given to the dynamic processes that allowed the uplift of an accretionary wedge from below sea level to 5 km above sea level. The compression forces like those involved in the collision of India with Eurasia must be constant 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.

12 Tectonic Movements and Subduction are Driven by Separate Forces

12.1 Introduction

Section 6 dealt with the circumferential forces that are considered to be responsible for the break-up of a supercontinent and the moving of the detached continental plates to the lighter side of the Earth. This approach yields an alternative lithosphere recycling model compared to the Wilson Cycle which is based on the heated circulating currents proposed by Hess. This section examines the forces responsible for subduction as a function of the movements of the continental plates as determined by the circumferential forces and the gained momentum resulting from its acceleration.

12.2 The forces associated with tectonic movements and subduction

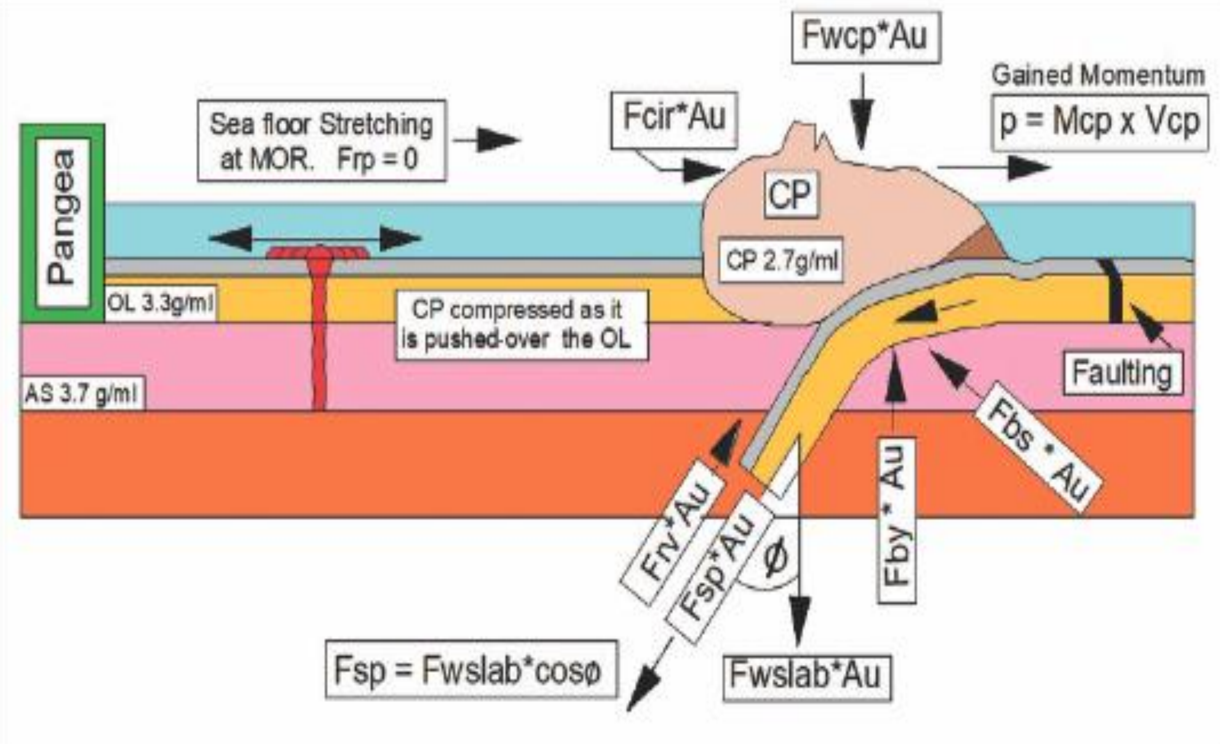


Fig 34. Principal Forces associated with Tectonic Movements and Subduction.

The contribution of each force will be appraised in the text and illustrations

This treatise investigates whether the present understanding of subduction, from the perspective of the higher density oceanic crust sliding under the lower density continental crust at convergent margins, is responsible for tectonic plate movements. Petrological changes associated with the subducting lithosphere, the formation of the accretionary wedge, the trench, and volcanic island arcs, have been and still are the subject of intense research.

In fact, the understanding of the operation of subduction zones stands as one of the great challenges facing Earth Sciences in the 21st century and 'will require the efforts of global interdisciplinary teams' (R.J. Stern)[62]. This treatise examines the forces responsible for (1) the break-up of a supercontinent (Pangea is used as an example) and (2) the initiation of the subduction process.

Arguments are put forward in the following sections to demonstrate that subduction is a consequence of tectonic plate movements rather than being the driving force. In doing so, the concept of momentum is introduced here into the study of tectonic plate movements. From Fig 34 and using the notation above, the parameters describing the forces to initiate tectonic plate movements and subduction may be stated as follows:

- Tectonic plate driving force (N) = Fcir * Au
- The gained momentum (p) = Mcp x Vcp … will influence the movement of the CP
- Subduction force (N) = (Fcir * Au + Fwcp * Au) + Fwslab > (Fby * Au + Frv * Au +Fbs * Au)

12.2.1 Forces associated with the breakup of a supercontinent

1 Fcir = Circumferential stress = $MR\omega^2E\pi/4$ N m^{-2} (Section 6 describes the derivation).

2 Fcir * Acp = Circumferential tensile force applied to a cross-sectional area of the continental plate riding on the asthenosphere. In this treatise, this force is credited as being responsible for the break-up of supercontinents and pushing the CPs from the heavier to the lighter side of the Earth.

3 Fcir * Au = Circumferential tensile force on an element of CP

4 Vcp = Velocity of CP

Whilst attached to the supercontinent, the relative velocity (Vo) of the locked together plates will be zero. Once split away by the circumferential tensile force, the individual plates will be accelerated from zero velocity to the present velocity (Vcp) of c.11-20 mm/year by the differential circumferential forces. It is difficult from an engineering perspective to see this acceleration being due to variable heated currents. Once on the move, the CP will acquire momentum (p) which is equal to the mass of the CP x Vcp. This is expressed as

5 p = Mcp x Vcp

6 Mcp x Vcp = Imparted momentum to the CP

7 Frp = Ridge-Push.

The force attributed to 'Ridge Push' at spreading ocean ridges is now considered to be insufficient to generate significant plate movement[13,16,27,38,47,49]. In contradiction, Billen[2] calculates the ridge force to be of the magnitude F = 1.59×10^{11} N/linear meter (N m^{-1}). The distance between the ridge and subduction zone is quoted as 5,000 km. The noticeable lack of distortion of the paleomagnetic stripes either side of the MOR (Fig 3, Section 2), demonstrates the absence of a lateral compressive push force. As such, this force is considered negligible and is thus discounted in this treatise.

12.2.2 Forces associated with subduction

1 Fsp = F(Slab-Pull)

= Fwslab * cos Ø where (wslab) = the weight of the descending (subducting) OL slab.

This is the downward force owing to the weight of the slab as it descends towards the mantle (see Section 2, Fig 6 - Hess model).

2 Frv = combined viscous drag and friction forces.

The forces that oppose the downward motion of the slab are normally calculated as a function of the descent velocity of the slab. However, in practice (as this movement is slow and measured in distance/year), the velocity element is negligible in terms of the force equations.

Another problem is that the viscosity, as well as the possible buoyancy forces, will differ between the top and underside of the slab owing to the temperature difference between them and the composition of the descending slab. As such, the magnitude of these forces will be difficult to quantify from first principles. However, it may be possible to infer an overall retarding force from the total force equations presented in this treatise. For a first order calculation, both the above forces may be treated as an inefficiency factor that is <1

3 Fby = F (Buoyancy).

The lithosphere is relatively buoyant at the beginning of any subduction process due to the density difference between the lithosphere and upper asthenosphere. Fig 28 shows the higher density (3.3 x 10^3 kg m^{-3}) oceanic lithosphere subducting under the lower density (2.7 x 10^3 kg m^{-3}) continental lithosphere. Both layers, however, rest comfortably on the higher density (3.7 x 10^3 kg m^{-3}) upper mantle.

An external force must therefore be applied to push the oceanic lithosphere (3.3 x 10^3 kg m^{-3}) downwards into the upper mantle (3.7 x 10^3 kg m^{-3}). The force needed to overcome the upward buoyancy forces is derived from the greater weight (albeit of lower density) of the overriding continental plate owing to its greater mass. For the purposes of this study, the buoyancy force and isostatic equilibrium force are taken as being equal.

4 Fbs = F (Bending stress) factor of the subducting oceanic lithosphere:

If the subducted OL is treated as a loaded cantilever, then the portion of the force owing to the weight of the overriding CP causing the deflection, rather than the portion dealing with the buoyancy or isostatic equilibrium, may yield the magnitude of the bending stress to an acceptable uncertainty value.

5 Fwslab = F (owing to the weight of the descending [subducting] OL slab):

As the CP is forced away from the supercontinent (SC) by the circumferential forces, the bulk and weight of the CP will push the oceanic lithosphere under it into the asthenosphere (i.e., the ductile upper mantle) and finally into the lower mantle. Seismic observations have shown that a 'knee bend' forms in the oceanic lithosphere (OL) as it bends downwards as a 'slab' into the asthenosphere. The 'slab-pull' force associated with the weight of the descending slab is currently considered to be the major force aiding subduction and tectonic plate movements. The resistive forces associated with slab-pull are essentially friction and viscosity.

6 MCP = Mass of CP.

7 Fwcp = (Downward force (Mg) owing to the weight of the overriding continental plate).

12.2.3 Numerical values of the various forces

In solving for the numerical values of the forces involved in the above general equation, many factors need to be considered. These include upward buoyancy forces, pressure, the temperature gradients to describe the density (and hence the slab weight variations in the asthenosphere), isostatic considerations, and the variable water content and its effect on viscous drag coefficients. Irrespective of the approach taken, there is no consensus regarding the different values obtained between different authors. For ease of understanding, the simplified format of the equations will be considered in this section of the treatise.

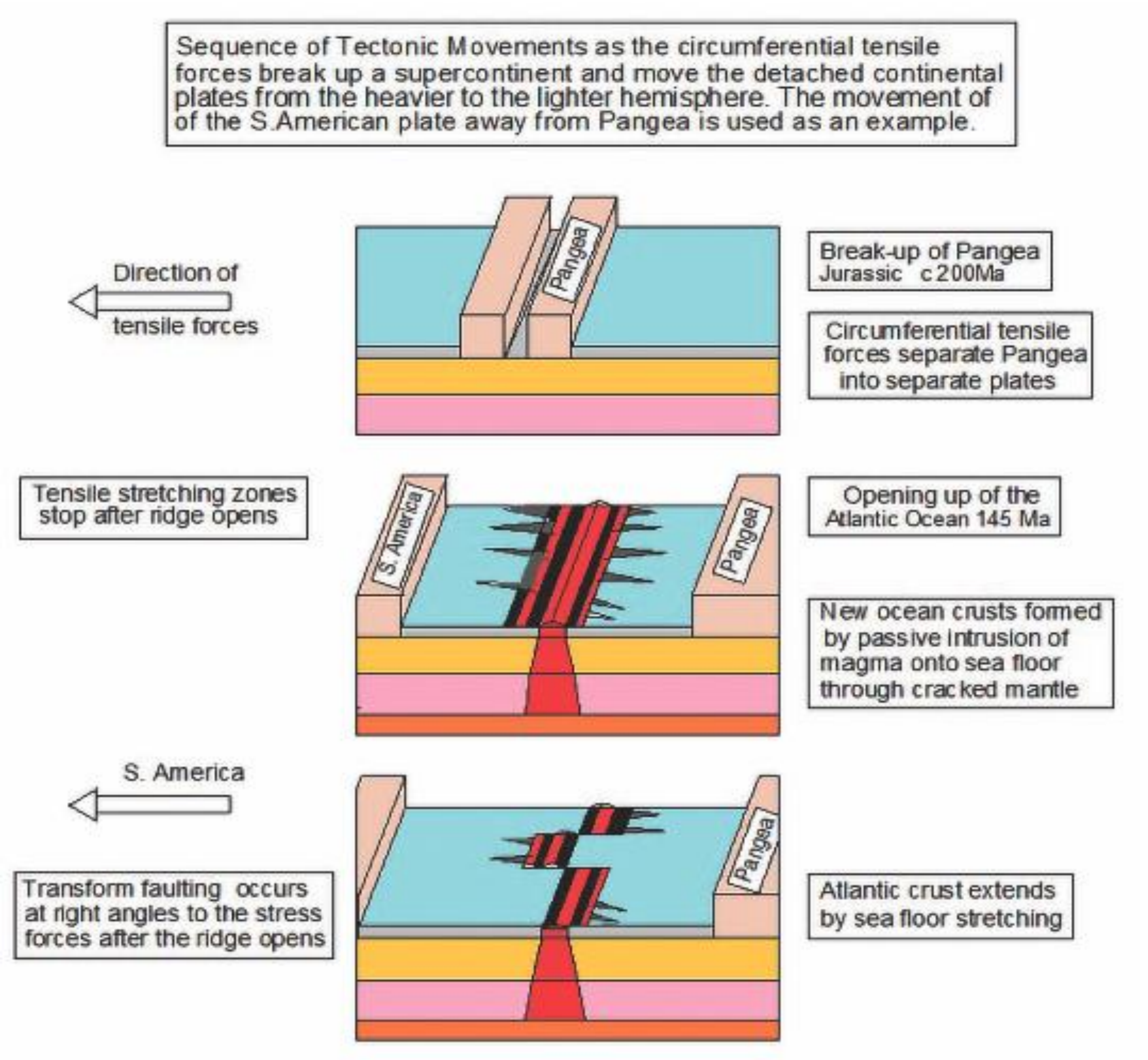
This is in keeping with the remit of this research work which is concentrated on the circumferential forces associated with the rotational velocity of the Earth rather than the processes associated with subduction.

12.3. Stage 1 Break-up of a supercontinent and sea floor stretching

Once separated by the circumferential tensile forces, the CP will gather momentum as it moves away from the supercontinent, an ocean opens between them and in doing so creates a new sea floor. Previously, the Hess model attributed this CP movement to a combination of convection currents, slab-pull, and ridge-push forces. Fig. 35 illustrates the CP movement based on forces associated with the rotational velocity of the Earth.

In trying to establish that the differential circumferential forces are sufficient to break up supercontinents, it should be borne in mind that the tensile strength of the oceanic lithosphere varies considerably with age, composition, and thickness. The older OL (>10 Ma) is mechanically able to withstand lithospheric forces such as tectonic interactions, whilst the younger OL is much thinner with substantially reduced mechanical properties owing to its higher temperature. As such, rift and ridge activity are more likely to occur in the younger OL[38,39]. Based on this premise, the rift opened within the supercontinent will be along the weakest lines that allow separation to occur and magma will readily extrude onto the floor of the ocean opening between the separating blocks. The lack of distortion of the paleomagnetic lines demonstrates the absence of any viable ridge-push compressive forces involved. Thus, the widening of the new ocean will be by 'sea floor stretching' rather than 'sea floor spreading'. Under these circumstances, the ridge force imparted by magma intrusion can be taken as zero insofar as its contribution to pushing tectonic plates apart. Using Pangea as an example, it can be observed that as the South American plate moves west, the Mid-Atlantic Ridge will form under the applied tensile forces with magma extruding and accumulating onto the sea floor. Apart from the evidence supplied by the dating of the paleomagnetic lines either side of the ridge, it is noted that the ridge has in fact moved about half of the total distance moved by South America since the initial break-up in the Jurassic period. Thus, the previously referred to[15] 'sea floor spreading' can be reclassified as 'sea floor stretching'.

Fig 35   Stage 1: Sea Floor Stretching



In this respect, Fig 35 reinterprets the original Hess model of subduction by circulatory convection currents with one that shows tectonic plate movements as being a function of the differential tensile stress forces associated with the constant rotational velocity of the Earth. This interpretation does not invalidate research work at the convergent and divergent margins as the petrological and geological outcomes will be the same.

12.4 Stage 2: Subduction initiated

The initial movement of the CP will be a function of the Fcir rifting the CP away from the supercontinent. This will be followed by the Fcir accelerating the CP from zero velocity to a continuous movement velocity (Vcp). During this acceleration, momentum (MCP x Vcp) will be imparted that will keep the CP on its course to the ‘lighter’ side of the Earth (Section 6). Subduction of the underlying OL by the downward force owing to the weight of the overriding CP (Fig 36) will begin once the separation movement is underway.

During the initial CP-to-OL engagement it is unlikely that the subducting OL will have been bent significantly downwards into the slightly higher density asthenosphere. As such, the slab-pull force would be negligible. Despite the lack of the slab-pull force, the CP's (e.g., South America going west and Australia going east) continue to move continuously away from the area of maximum circumferential stress at Pangea. (Please note that the position of the COM will change slightly as will the area of maximum stress over extended time periods.) This observation brings into focus the proposition that the slab-pull force may not be a major requirement for the subduction process. Furthermore, it becomes obvious that the forces moving the CP over the oceanic plate are imparted momentum or the circumferential forces. At Stage 3, the forces associated with subduction may be expressed as follows:

(As there is some uncertainty regarding the principal CP driving force at this stage, the term 'resultant' is used.)

Subduction Force (N) = Resultant (Fcir * Au + Fwcp * Au) > Fby * Au + Fbs * Au

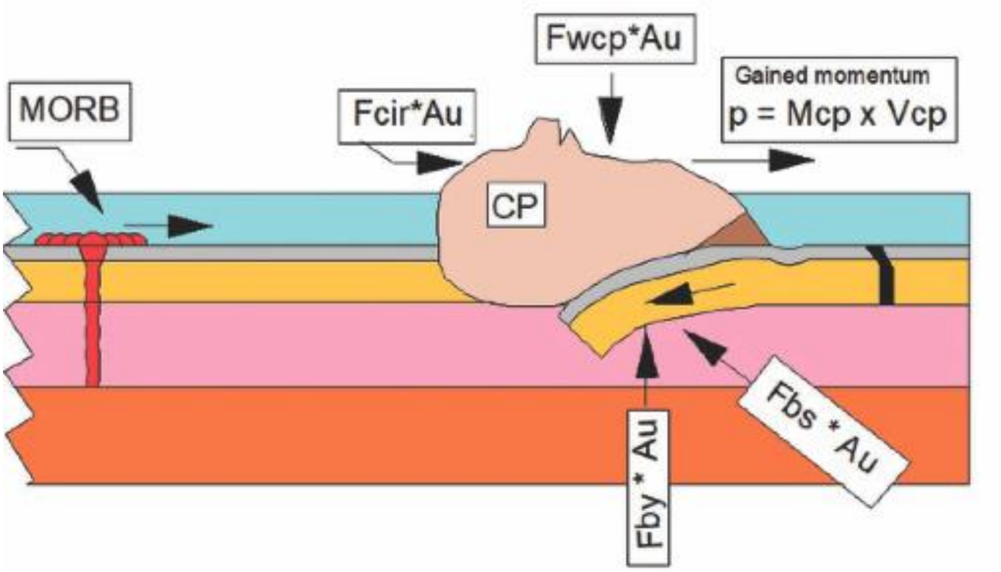


Fig 36 Stage 2: Subduction of OL initiated by the downward force owing to weight of the overriding CP

12.5 Stage 3: Slab-pull force established

As the OL is bent downwards (Fig 37) by the force of the weight of the overriding CP into the asthenosphere, the slab-pull force minus the resistive forces of viscosity and friction must be taken into consideration. The apportioning of the buoyancy forces is difficult as the OL's petrology continuously alters with changes in depth, temperature, and water content. These changes make it difficult to attribute numerical values to this force. The resistance to the bending stress (Fbs) or creation of the 'knee' in the subducting oceanic lithosphere must also be considered. Like the buoyancy, the physical parameters of the OL are variable with respect to composition and age[38].

The basic subduction equation is thus expanded as follows:

Subduction Force (N) = Fwcp * Au+ Fsp * Au > Frv * Au + Fby * Au +Fbs * Au

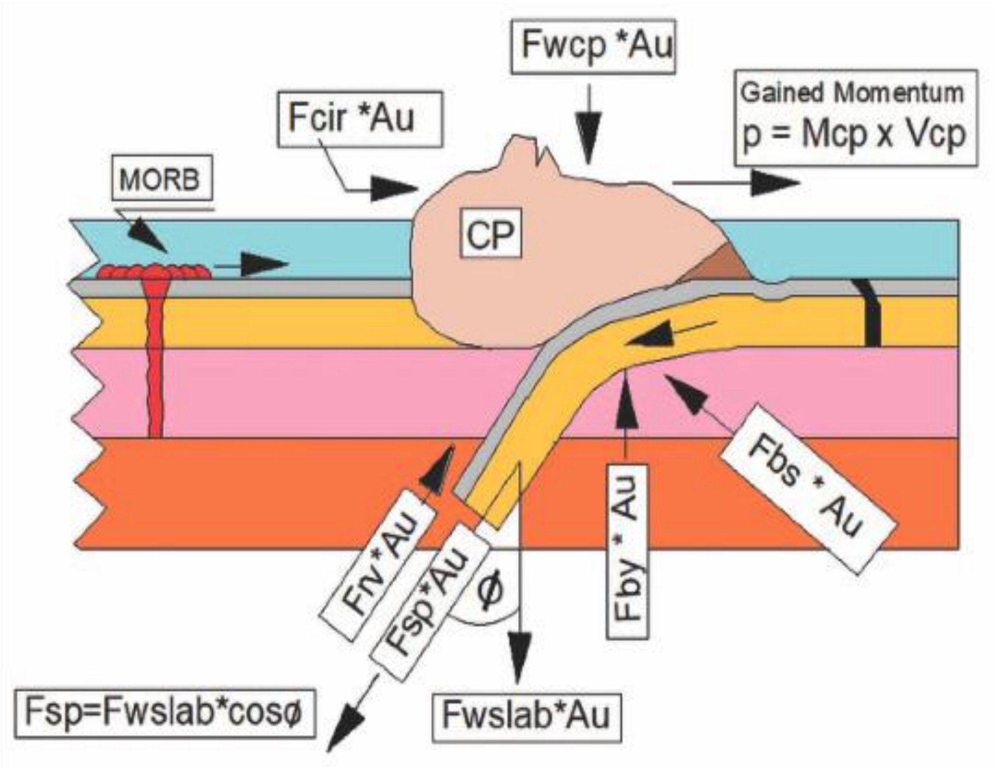


Fig 37: Stage 3 Slab-Pull force established

12.6 Stage 4: Descending slab detaches; movement of CP is unaffected

The inevitable loss of the slab (Fig 38) either by break-off or melting at the asthenosphere/lower mantle boundary will result in the almost total disappearance of the slab-pull (Fwslab) and the associated retarding force (Frv). The upwards buoyancy force requirements will be partially lowered. The momentum gained by the acceleration of the CP will keep the CP moving despite the loss of the slab-pull force (Section 8).

The subduction equation now becomes:

Subduction Force (N)= Fwcp > Fby + Fbs.

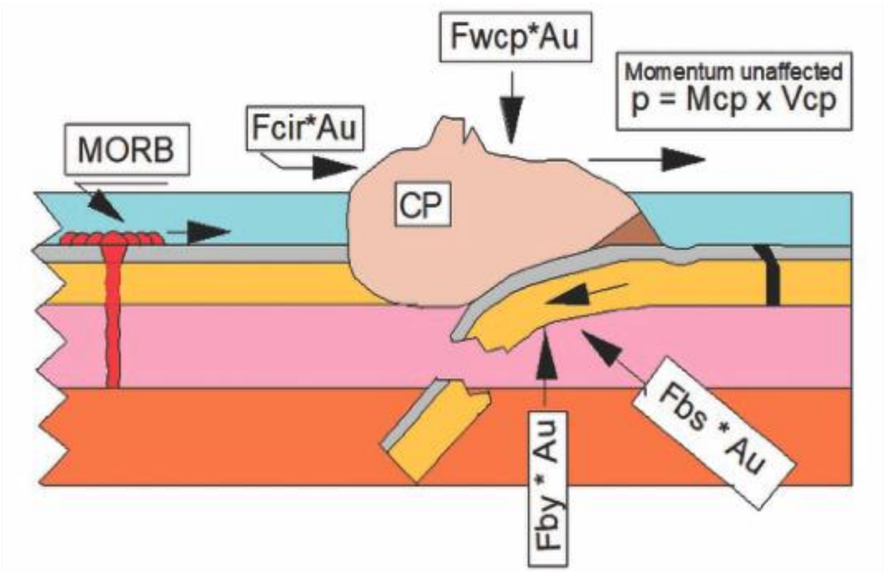


Fig 38: Stage 4 Slab detaches. FSP =0. Movement of CP is unaffected by loss

12.7 Stage 5: Restart of the subduction cycle

CP moves at Vcp, the descending slab lengthens and (Fwslab - Frv) restarts (Fig 39). This is also shown in Fig 34. The momentum gained by the CP on its movement away from the supercontinent (Pangea) will be unstoppable unless there is a CP-to-CP collision. The continual motion of the CP will ensure that after the loss of the slab, subduction will continue, and a renewed slab will be created. There is also a distinct possibility that loss of the slab will cause roll-back which in turn may account for the distortion and compression of the CP. The equation describing the immediate subduction force after slab detachment will, until slab growth becomes significant, will be

Subduction Force (N) = Fwcp * au > Frv + Fby + Fbs.

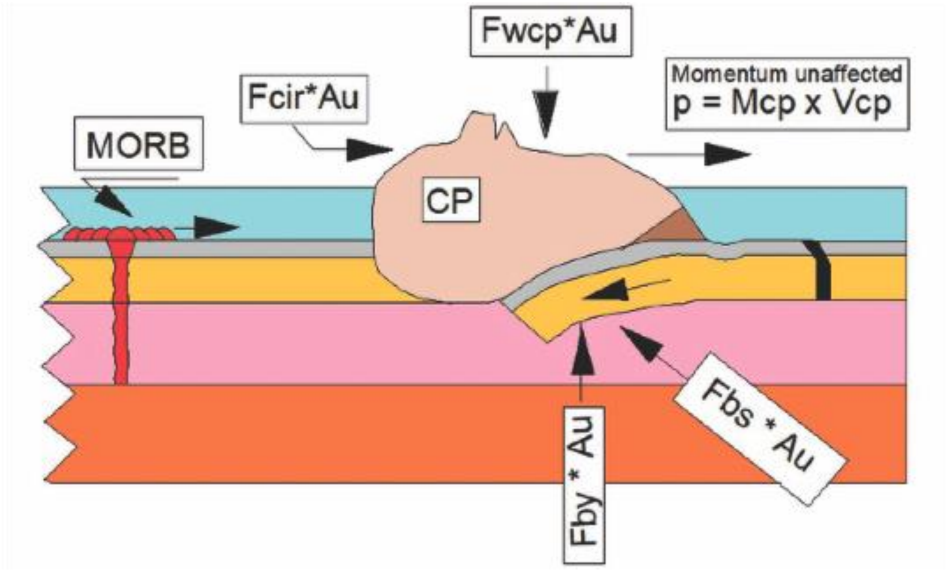


Fig 39: Stage 5 CP is kept moving by momentum and slab growth sequence re-starts

12.8 Pictorial summary of the forces driving plate tectonics and subduction

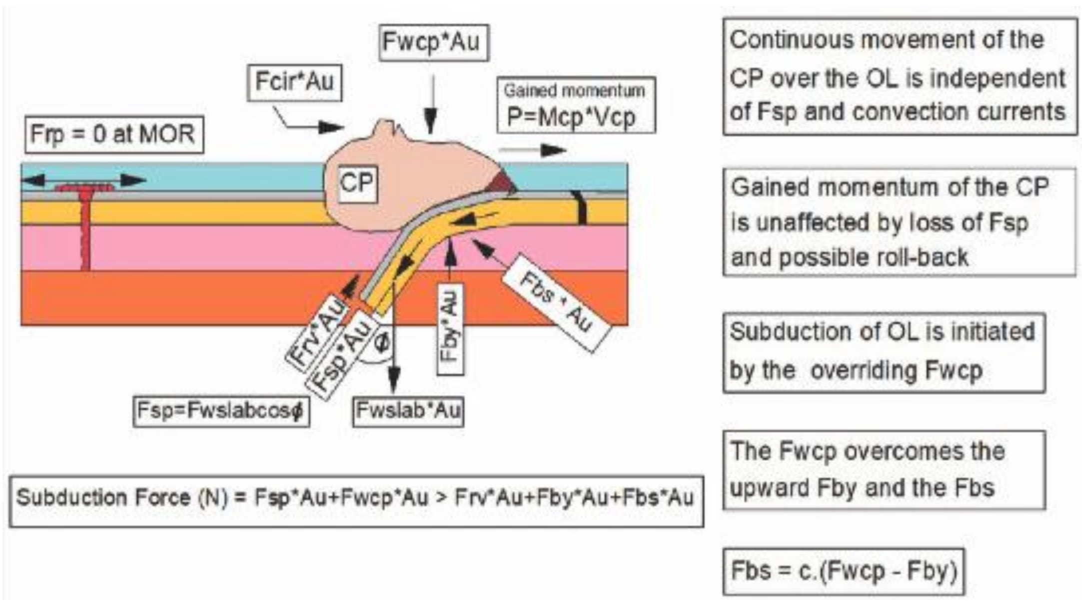


Fig 40: Pictorial summary of the forces driving subduction

12.9 Examples where subduction is related to orogenesis

12.9.1 Oceanic plate to oceanic plate convergence: subduction and obduction

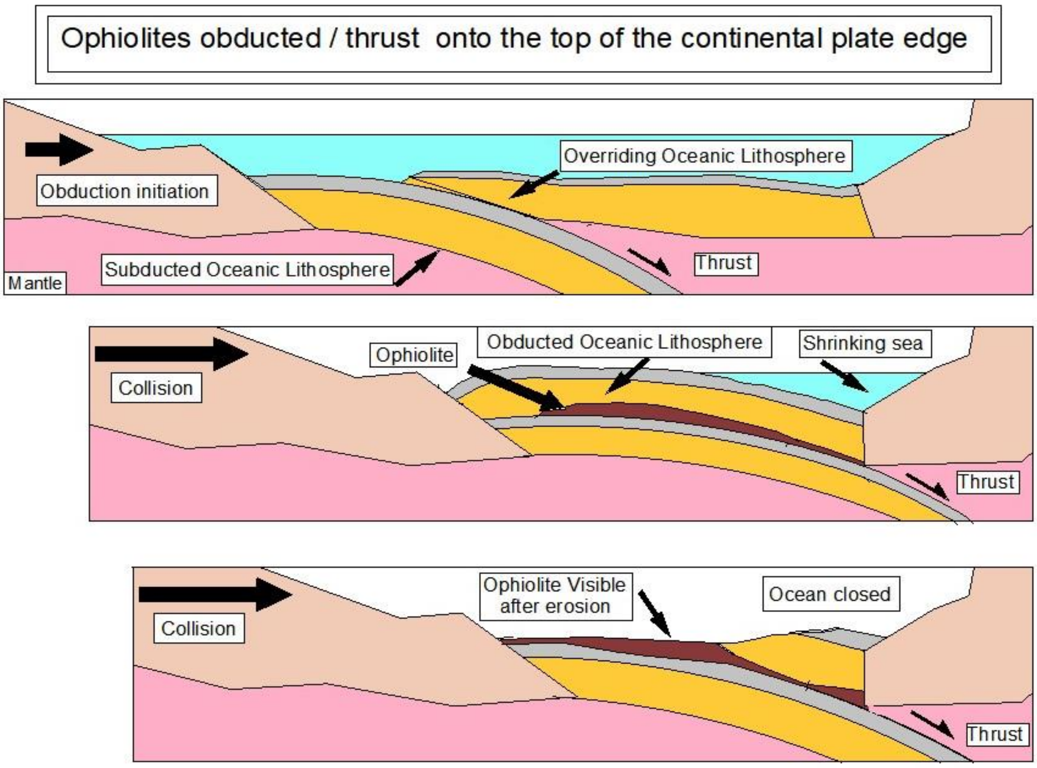


Fig 41 – Compression of OL during CP-to-CP compression

Subduction begins when two plates collide to form a convergent boundary. Here the collision of two continental plates (CP) is preceded by the compression of the oceanic lithosphere (OL) between them. Fig 41 illustrates the initial sequential actions at the OL-to-OL boundary.

The illustration infers that the upper plate has a lower density and smaller profile than the lower plate. That stated, no relative movement will take place unless a compressive force is applied. Compressive and tensile forces owing to convection currents have been challenged and discounted in Section 2. At present, there is still no consensus regarding the flow patterns of the convection currents at the mantle-core boundary. Perhaps a notable example is the compression of Greater India as it collided with the Eurasian plate

Taking this argument forward, it is important to consider the process of obduction. Obduction is the process whereby the higher density oceanic lithosphere is thrust over a lower density opposing plate instead of being subducted. Typical examples are seen in the Himalayas, Cyprus, and in the movement of the Arabian plate towards the Eurasian plate in Oman. This is illustrated by the exposure above sea level of the ophiolite rocks, which are slices of the uppermost oceanic lithosphere which have been thrust onto the continental crust.[5,7,45]

Ultimately the collision between the two oceanic plates will result in the continental plates on either side of the shrinking ocean coming together to form a continental plate to continental plate convergence. The oceanic plate to oceanic plate convergence is essentially a system whereby the two plates are subjected to a pincer movement. As an example, this situation is noted at the closing of the Tethys Ocean when the Indian and Arabian plates, together with microplates in the Mediterranean region, collided with Eurasia at around 50 Ma.

12.9.2 - Example of orogenic activity at CP-OL convergence

While the purpose of Figs 34 and 39 is to show the principal forces, Fig 42 shows in cartoon form the creation of the orogenic process in which the CP, OL and the AW are distorted at the convergence zone.

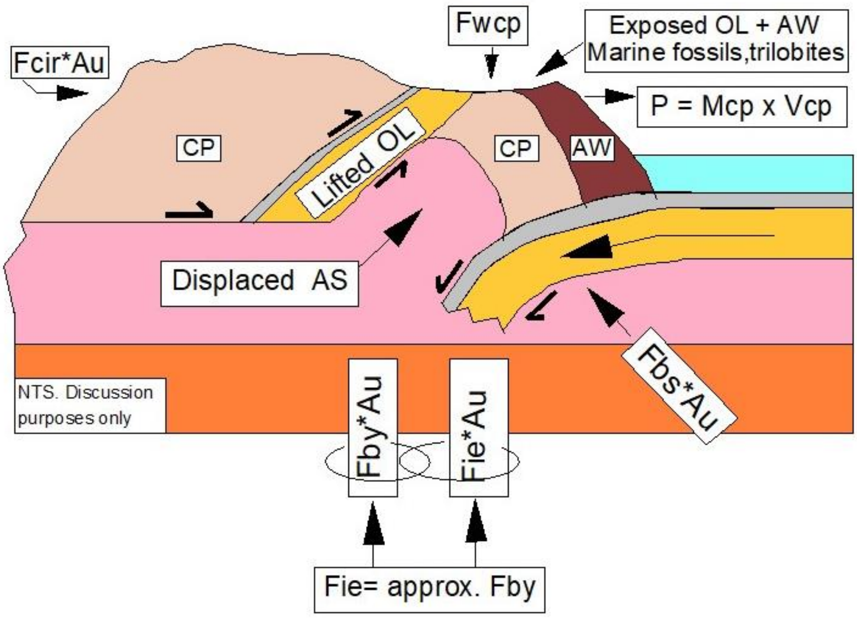


Fig 42: The upward displaced volume of the AS by the subducted OL.
Fby contributes to isostatic equilibrium, for illustrative purposes only

The movement of the South American plate over the Nazca plate is an example, in that marine fossils are found high in the Andes in Bolivia. The volume of the OL being pushed down into the AS will generally result in the upwards movement of an equivalent weight of the ductile AS. This in turn will also cause the overlying OL and AW to move upwards as well with the possible intrusion of magma from the AS into the overlying CP. Erosion over time will expose the sequences.

A typical example is seen in the Altiplano in the Andes where marine fossils including Silurian trilobites can be found in the La Paz area of Bolivia. The convergence of the South American and Nazca plates also resulted in the N-S aligned fold mountains known as the Cordilleras.

An interesting aspect of this convergence is that, if the volume and thus the weight of a representative element of raised AS can be estimated in addition to the weight of the overriding CP and the deflection of the OL, then it may be possible to estimate the bending stress of the OL. The first order equation considering the OL to be a loaded cantilever would be:

F(wcp) – F (weight of displaced AS) = Fbs.

Knowing the deflection of the ‘knee’ in the OL from seismic studies, the bending stress can be estimated.

12.10 Summary.

Separation of forces for tectonic movements from subduction processes

This is a major departure from most current thinking which considers tectonic plate movements to be a direct function of subduction of the oceanic lithosphere, and by implication, the acceptance of heated convection currents as the primary driving force.

As described previously in Section 6, the circumferential forces were calculated and established by approaching this problem in terms of a thin shell moving relative to the mantle. This made it possible to consider which elements of the tensile force are responsible for putting the Pacific Basin under compression and the African plate under tension. The African Rift Valley is today a case in point.

Thus, the movement of a detached CP will be a direct function of the momentum gained as its velocity is accelerated to Vcp. The movement of the CP will not be affected by the initiation, growth and loss of the descending slab which are all a function of the physical and chemical properties of the OL with respect to the underlying mantle.

As such, subduction cannot be credited with controlling tectonic movements.

While the upward buoyancy force on the lithosphere and downward forces bending the OL may have been lowered, the overall effect on the movement of the CP appears to be unaffected.

To date no evidence has been found in published literature that suggests partial stoppage or the slowing down of a moving CP due to the loss of the slab-pull force and its resistive forces (Frv).

Fig 43 shows the sequence of stages illustrating the mechanics of supercontinent break-up and subduction.

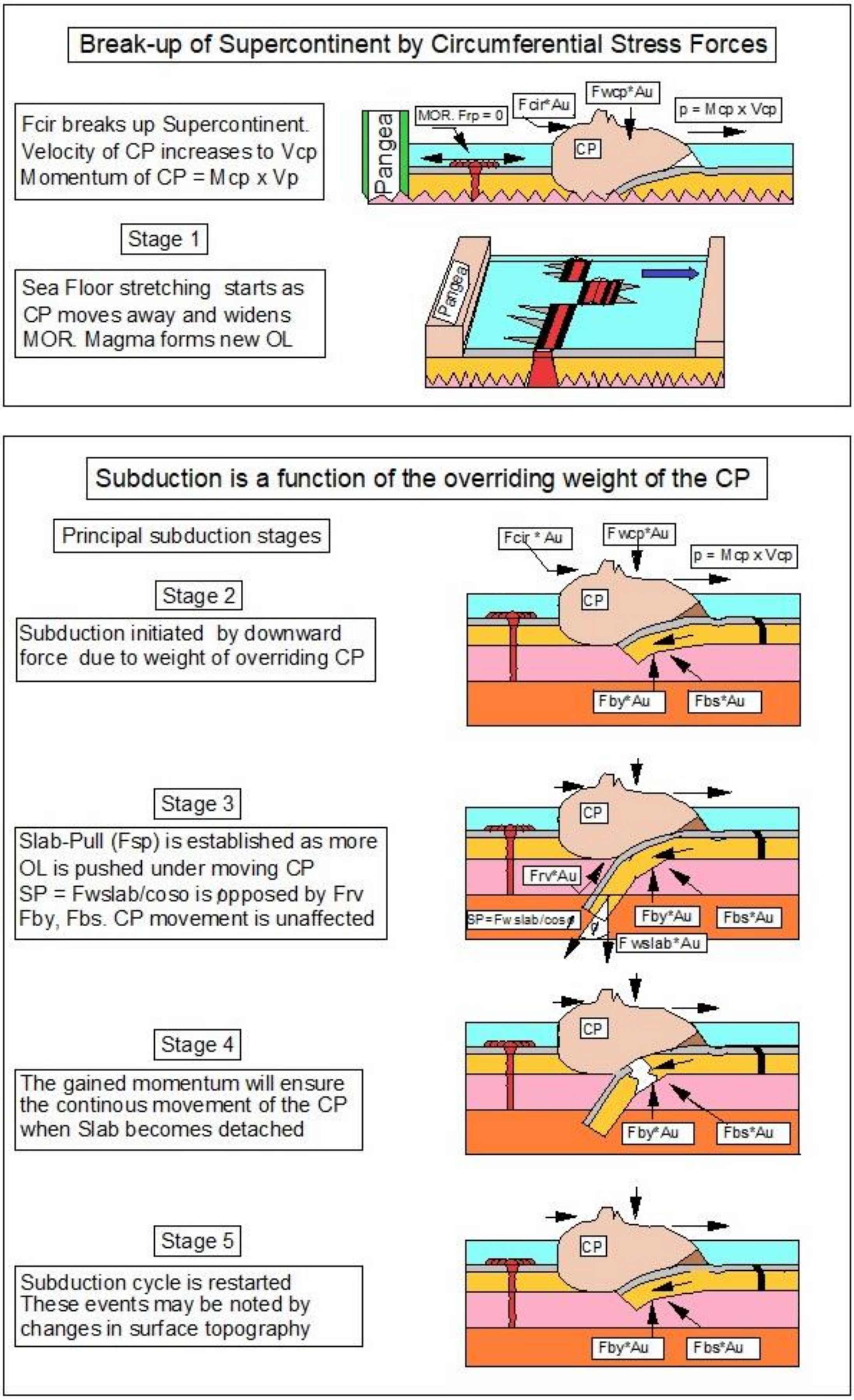


Fig 43. The Separate forces of Supercontinent Break-up and Subduction

13 Regional Metamorphism

To maintain the sustained unidirectional movement of Pangea northwards followed by the east and westward movements of crustal plates either side of the central part of the African plate, the applied forces must be both substantial and have a stable permanent origin. It is this requirement that will cause the relative movement of the continental crust, with its variable underside topography, to be forced over the almost mountainous terrains of the oceanic crust.

The resistance to motion will result in a plethora of metamorphic processes varying from high- and low-pressure water injection, to high pressure/high temperature regional metamorphism. Both would change the crystal structure and composition of the rocks involved. This is in addition to the pushing, tilting, deformation, and uplift of sedimentary sequences from their original horizontal position thus forming the mountain ranges we are now familiar with.

The forces associated with the above-mentioned processes would need to be evaluated in conjunction with laboratory simulations and reported field observations to determine the realistic value of the circumferential force F and the applied pressure loads at the specific locations.

These processes are illustrated in Fig 44.

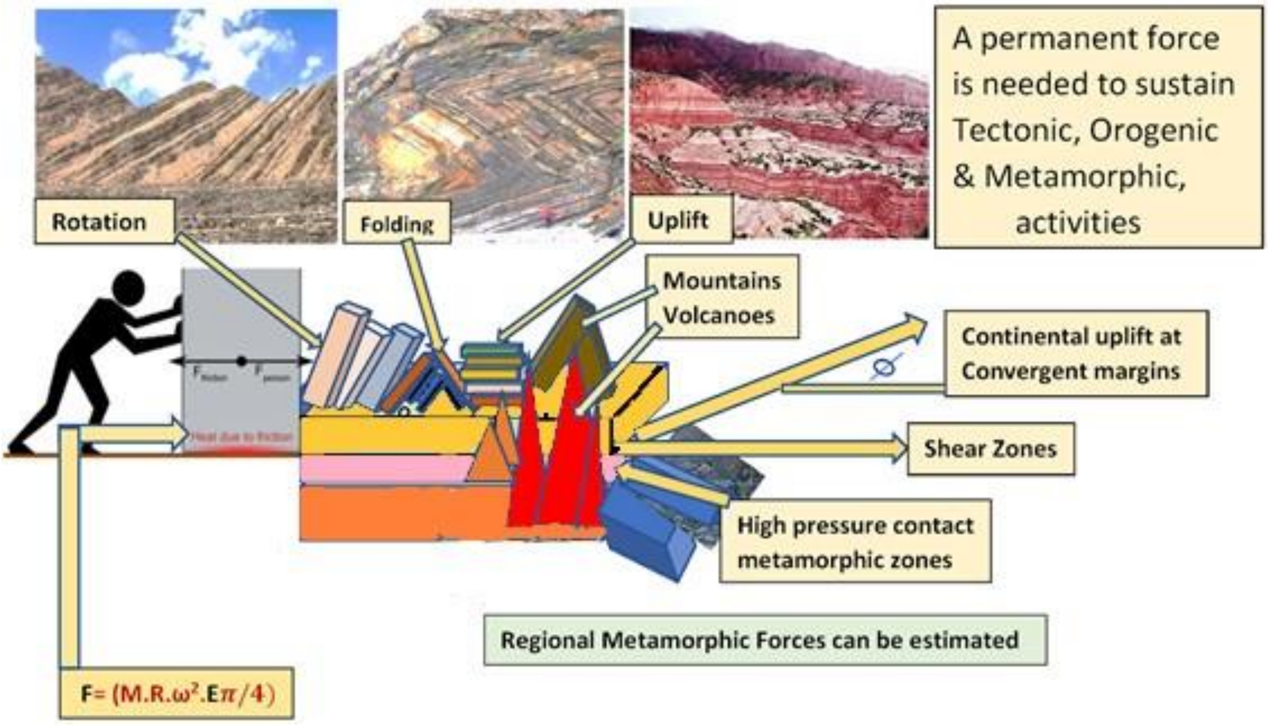


Fig 44 Continuous sustained forces are required for orogenic and metamorphism

14 Cycle of Lithosphere Regeneration

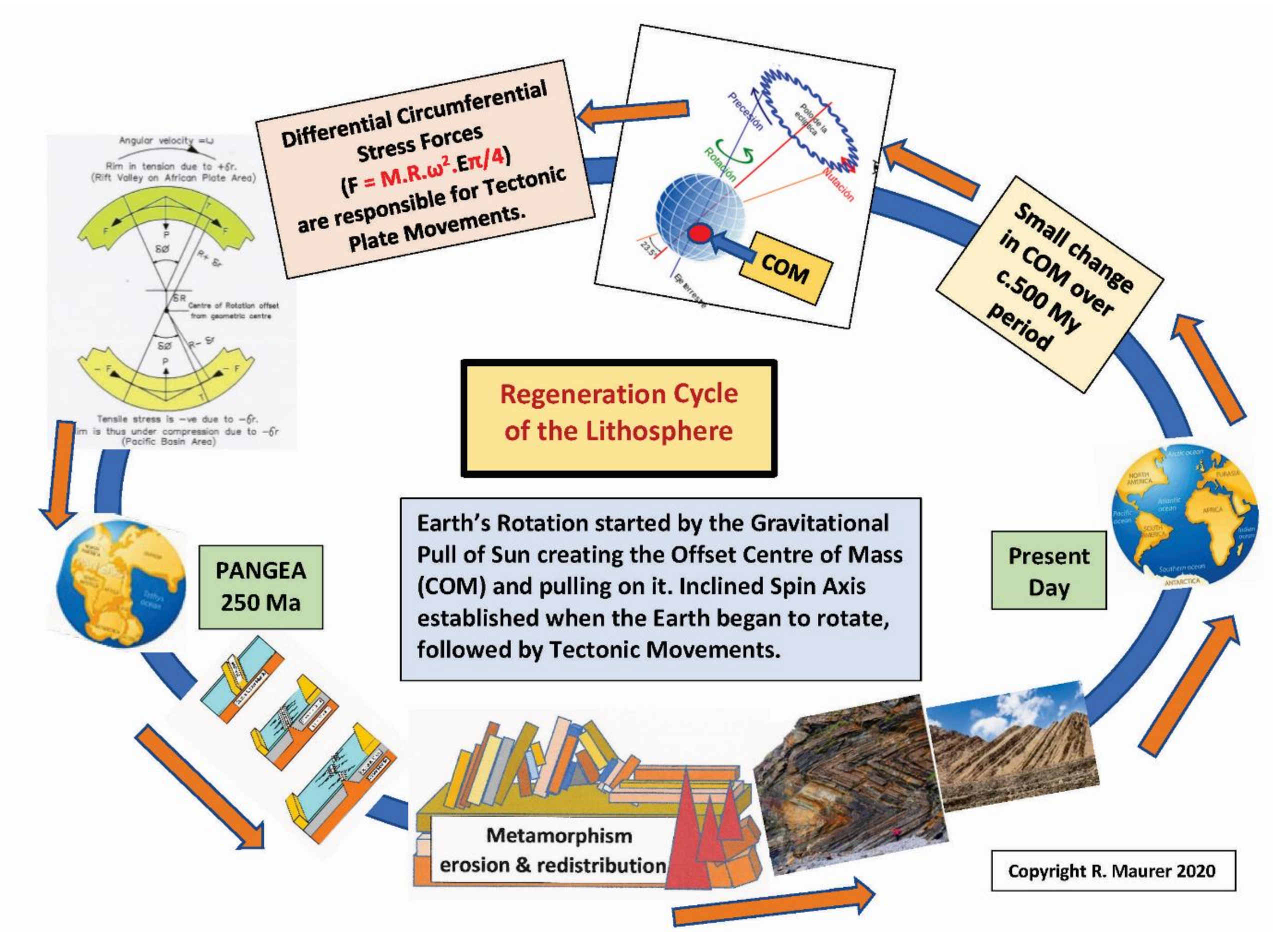


Fig 45 Regeneration Cycle of the Lithosphere

From the arguments put forward above, it is possible to construct the regeneration cycle of the Earth's continental and oceanic lithospheres as shown in Fig 45. The oscillating patterns known as the Milankovitch cycles, which are associated with the rotating/orbiting unbalanced tilted planets, will create circumferential stresses in the outer rim which will cause the crustal masses to move from the heavier to the lighter side. In doing so, they will undergo continuous changes in configuration and size through boundary changes, travel direction and topography.

Typical types of force-driven metamorphic and topographical changes, which include orogenic and volcanic activity, igneous pluton formation and changes in mineral composition are illustrated in Fig 46.

The formation of new plates and their subsequent denudation or destruction over geological time, due to erosion and subduction, will cause the ever-changing lithosphere to be continuously redistributed and recycled over the Earth's surface.

Unlike the Wilson cycle of lithosphere regeneration which is dependent on heated convection currents within the mantle, this proposed regeneration cycle has, as its starting point, the differential circumferential tensile forces that are developed in the outer rim of the Earth. These estimated forces (Section 6), which are related to both the offset Centre of Mass and constant rotational velocity of the Earth, have been demonstrated to be sufficient to split supercontinents apart and disperse the detached continental plates from the heavier hemisphere to the lighter hemisphere.

While the mass of the crust is negligible compared to the total mass of the Earth and will not affect the Earth's moment of inertia, the dispersed crustal masses will recombine over the surface in an arguably predictable manner.

It has also been demonstrated that, by considering the opening of oceans between continental plates (CP) as a function of their gained momentum as they accelerate away from a supercontinent, the need to explain ocean floor spreading by convection is removed. The tension across the mid-ocean rift reduces pressure within the upper mantle, lowering the melting point of the mantle material and allowing the resultant magma to rise as ocean ridge basalts, thus widening the ocean.

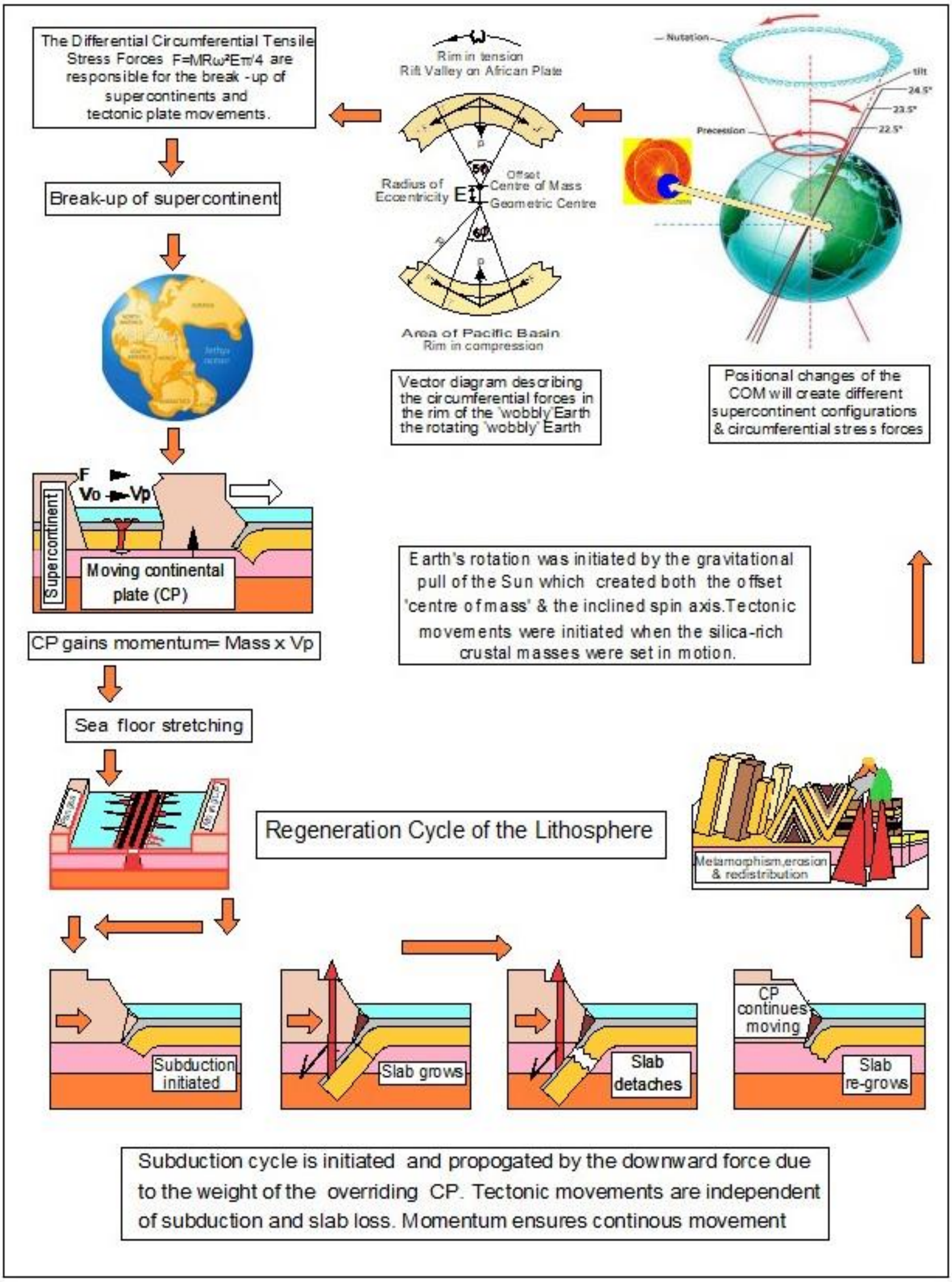


Fig 46 Continuous Regeneration Cycle of the Lithosphere

15. 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 the Jurassic period, 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 behaviour 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 is coincident 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 during 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 treatise has principally demonstrated:

1. That the forces responsible for the break-up of a supercontinent and tectonic plate movements are very separate and distinct from
2. The forces initiating and propagating subduction.

Furthermore, the approach taken also allowed the following unexpected findings and conclusions to be noted:

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 all rotate with the same hand (as seen from above the north pole) as does the Sun, and have a similar tilt angle to the Earth with a similar diurnal rotation period (other than Mercury, Venus and Uranus).
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. The introduction of the concept of 'momentum' to a moving continental plate (CP) is applied to the initiation and propagation of the subduction cycle.
5. The initiation of subduction of the oceanic lithosphere (OL) is shown to be a function of the downward forces created by the weight of the overriding continental plates. It is this action that forces the OL into the mantle.

6. As the loss of the slab-pull force by the eventual detachment of the sunken oceanic lithosphere (OL) does not impede the movement of the CP, subduction is shown to be a consequence of the movement of tectonic plates rather than the driving force.

7. Convection currents in the mantle are thus shown to have a secondary rather than an active role in tectonic plate movements.

8. The concept enabled the development of an alternative cycle of continuous lithosphere regeneration that challenges the presently accepted Wilson cycle.

9. The initial northward movement and the break-up of Pangea may well have resulted from the centripetal upward and outward forces separating Antarctica from Pangea followed by the differential circumferential stress forces acting in concert with the radial centripetal forces at the higher latitudes, in moving the continental plates towards the Pacific Basin.

10. The determination that the forces primarily driving tectonic plate movements are directly related to the rotation of the Earth has, by implication, made convection currents and magma intrusion take a secondary passive role.

11. The forces involved in the 'Cycle of Planet Regeneration' shown in Fig 46 allows each stage to be examined and where possible estimated.

12. The introduction of the following new terms into the geological vocabulary is proposed:

    a) 'Differential Circumferential Stress Forces '(DCSF)

    b) 'Pushed Continental Crust' (PCC)

    c) 'Radius of Eccentricity'

    d) 'Gravitational Crank Coupling (GCC) and

    e) 'Cycle of Continuous Lithosphere Regeneration' (CLR).

16. Case study 1: The Influence of Momentum on the Movement of the Indian Plate from Gondwana to Eurasia

The breaking up a supercontinent by the circumferential tensile stresses is followed by the detached continental plate gaining momentum as it is accelerated from almost zero velocity. As the circumferential tensile force available for driving the CPs is substantially constant over long time periods (millions of years) the slow but unrelenting movement of the crustal plates from the heavier hemisphere (Africa) to the lighter hemisphere (Pacific Basin) is readily understood in the case of the westward movement of South America and the initial eastward movement of the Indo-Australian plates. However, a problem arises when trying to explain, using the Hess subduction model, the angular rotation, and the northeast movement of the Indian plate across the equator. Unlike India, Australia moved east and remained below the equator. India's movement started at c.140 Ma when it separated from Africa and continued until it began to collide with the Eurasian plate c.50-35 Ma (Fig IP1).

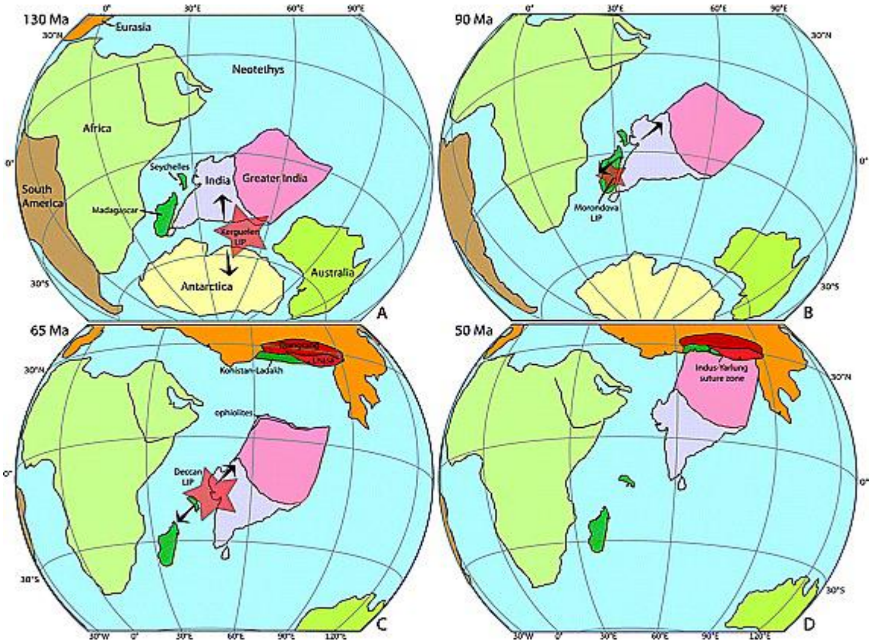


Fig IP1 NE Movement of Greater India 130 Ma to present [70]

16.1 Consideration of the gained momentum of the moving Indian CP

Originally it was this anomaly that led the author to consider the concept of momentum as being responsible for steering the Indian CP across the equator in a NE direction which resulted in its colliding with the Eurasian plate. As explained in Section 11, once a detached continental plate is accelerated from zero velocity (Vo) as part of a supercontinent to the velocity of a moving plate (Vcp) it will acquire the momentum to keep it in motion until halted at a convergent boundary. The spectacular formation of the Himalayan Mountain range is a prime example. As the accelerating forces giving rise to momentum are constant as is the CP mass to a large extent, changes in direction will be explained as being due to the partial loss of the retarding forces particularly that of viscous drag. It is thus postulated that the off-centre lowering of the viscous drag force by magma intrusion between the moving CP and the asthenosphere will skew the direction of travel. This section examines the events from the end of the Jurassic period to c.50 Ma just prior to the collision between the Indian and Eurasian plates[21,11].

16.2 Brief survey of published proposals regarding the NE movement of the Indian Plate from Gondwana to Eurasia

The overall speed at which the Indian plate moved NE from Gondwana to Eurasia as well as its noted periods of deceleration has been extensively studied[21,28,32,45,56,57,59,70,71,74,77] using a wide variety of approaches, some of which are summarized in this section. Where possible, the variation in the dating of events given by different authors is averaged. Alternatively, this treatise takes into consideration the influence the momentum of the Indian plate exercised in determining the actual NE route and the variation in the linear velocity as it moved towards Eurasia, as distinct from subduction-related processes alone. To date no evidence of historical documented work relating CP movement to momentum has been found. There is also divergence of opinion between the author and other contemporary research geologists in that subduction is considered by the author (Sections 9 and 10) to be a consequence rather than the driving force of continental plate movement. It is for the above-mentioned reasons that the following brief and abbreviated literature survey (compiled from the references cited) is used for introductory purposes only.

It is generally accepted that c.140 million years ago, India was still a part of an immense supercontinent called Gondwana, which covered much of the Southern Hemisphere. Around 120 million years ago, what is now India and Madagascar broke away and started slowly migrating north, at about 50 millimetres per year. In the late Cretaceous (100 - 80 Ma), the Indian Plate split from Madagascar and began rapidly moving north at c. 100 millimetres per year. As indicated above, the Indian plate started to converge with the Eurasian plate about 50 million years ago, giving rise to the Himalayas.

There is still debate regarding the collision date between India and Eurasia which is variously stated as being between 50 and 25 Ma. This is due in part to the lack of consensus regarding the extent of the shortening of the northern extension that made up a 'Greater India' as well as the movement of the African plate[71] against which the speed and position were plotted. Subduction of the ocean basin that formed between the Greater Himalayan fragment and India is one of the reasons used to explain the apparent discrepancy between the crustal shortening estimates. The Indian plate is currently estimated as moving north-east at 50 millimetres per year, while the Eurasian plate is moving north at only 20 millimetres per year. Other proposals state that the mantle plume that once broke up Gondwana might also have melted the lower part of the Indian subcontinent, which allowed it to move both more quickly and further than the other plates[10]. The remains of this plume today are credited with the formation of the Marion Hotspot (Prince Edward Islands), the Kerguelen Hotspot, and the Réunion Hotspot.

The changes in the velocity of the Indian plate on its NE passage to Eurasia is still subject to intense debate. Proposals vary from plume-driven tectonics[71,14] to partial subduction of the Neo-Tethys Ocean floor by Kious & Tilling[29]. Pusak and Steadman [53] suggested the reason the Indian plate moved so quickly was due to a double subduction system that relied on plume-push forces. Royden et al.[37] from Massachusetts Institute of Technology (MIT) state that India's fast drift velocity from 50 to 150 millimetres/year may be explained by the increased rate of magma escaping between two subducting plates, one being India and the other being another plate in the middle of the Tethys Ocean. If subduction is considered as the driving force, this would require an elliptical-shaped convection current system angled at about 60° to the supposed east-west currents driving the Australian plate. This supposition does not appear to be mentioned in the literature surveyed.

In contrast to subduction-based forces Doglioni[14] puts forward the argument that the westerly movement of the tectonic plates is a result of the thermally induced decoupling of the lithosphere from the asthenosphere which in turn substantially lowers the viscous drag at the interface. He thus postulates that it is this decoupling that allows for the lithosphere to be dragged by the gravitational pull of the Moon to exert a cyclical torque force on the excess mass at the Earth's bulge. The above model is used to explain the presence of the multiple plate boundaries with their variable modes of subduction. Seton[58] approaches the above movements within a modelled global tectonic movement framework. Several of her findings have been used to date the break-up of Pangea.

Yoshida & Hamano[76,77] used simulations based on temperature differences and thus differences in viscosity to explain that a major factor in the northward drift of the Indian subcontinent was the large-scale cold mantle downwelling that developed spontaneously in the northern Tethys Ocean, attributed to the overall shape of Pangea. The strong lateral mantle flow caused by the high-temperature anomaly beneath Pangea, due to the thermal insulation effect, enhanced the acceleration of the Indian subcontinent during the early stage of Pangea's break-up. Their study[76,77] suggests that the high-speed northward drift of the Indian subcontinent was likely caused by large-scale mantle downwelling that developed spontaneously in the northern Tethys Ocean. This action was attributed to the overall shape of the Pangea supercontinent. This result implies that the high-speed northward drift of the Indian plate and the resulting Indo-Eurasian convergence at around 50-40 Ma was pre-destined when the Pangea supercontinent was assembled at around 300 Ma.

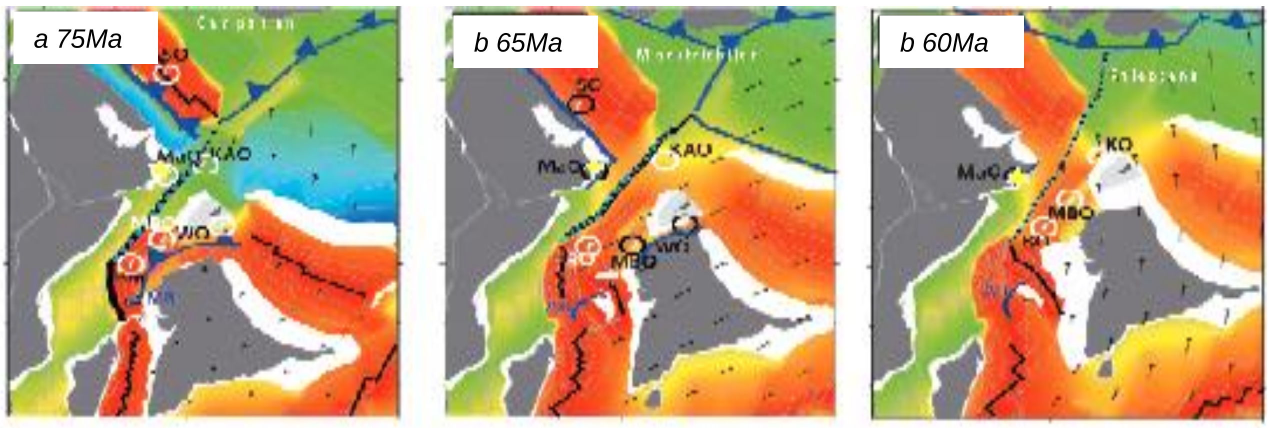
Chatterjee, Goswami and Scotese[56], apart from posing the question 'What exactly drives the plates?' postulate that this journey of the Indian plate was accompanied by the opening of the Indian Ocean via the forces associated with slab-pull due to crustal stretching resulting from the subduction of the Tethyan ocean floor beneath Eurasia. Furthermore, they have based the chronology of several major events (not listed here) which include both the decoupling from Madagascar (130 Ma) and the acceleration of the Indian plate (65-52 Ma) on tectonic and magmatic events. This implied that the creation of the multiple rift margins was by magma extrusion possibly due to the Reunion plume activity. They also state that, in the late Cretaceous when India split from Madagascar (90 Ma) with the spreading of the Central Indian Ridge (CIR), it started moving northwards and that subduction took place between India and Eurasia to facilitate the northward movement. It would appear from their paper that the two north-dipping subduction zones between Eurasia and India were active in the middle to late Cretaceous (120 to 90 Ma). They noted that when the continental lithosphere is put under extension it will break along pre-existing zones of weakness. The most conspicuous zones of weakness are:

(1) old continental collision zones where the lithosphere is still relatively warm, and

(2) areas recently weakened by mantle plumes and hot spots.

Gaina et al.[22,23] investigated the movements of plates in the Tethyan sea using information obtained from ophiolite complexes in conjunction with slab-pull forces to determine the historical positional movements of the Indian plate which included the oblique movement past the Arabian plate. The movements that are of interest are summarised in Figs IP2a, b and c in which

a 75 Ma refers to the date of obduction of the Masirah Ophiolite in SE Arabia,
b 65 Ma refers to the date of closure of the southern Tethys and the obduction of the Semail Ophiolite and
c 60 Ma refers to the date of acceleration and the final phase of the anticlockwise rotation of the Indian plate.



Figs IP2 a, b, c Oblique movement of the Indian Plate past the Arabian Plate (Giana 2014)

16.3 Alternative interpretation of the movement of India

This treatise differs in its approach to that taken by most of the authors quoted above in which the Hess model of subduction by heated convection currents is used as the major driving force. If subduction is considered as the driving force, then, as stated, and postulated above, an elliptical-shaped convection current system would need to be angled at about 60º to the east-west currents driving the Eurasian and the Australian plates eastwards and the South American plate westwards away from the nearly central African plate. It is unlikely and very difficult to imagine how the convection currents could remain separate and stable over a 145-150 Ma period in which the CP movements themselves linked to convection currents take place over great distances across many latitude zones. Over these time periods the transfer of heat through a conducting asthenosphere would destroy any vestige of directionality and would not be capable of sustaining the unidirectional movements of the different plates. In contrast, the forces related to the almost constant rotational velocity of the planet are predictable over long periods of geological time. By approaching the above-mentioned situation from the perspective of momentum-driven continental plates and sea floor stretching as distinct from ridge-force spreading, it is possible to offer a viable alternative explanation to describe the NE movement of India.

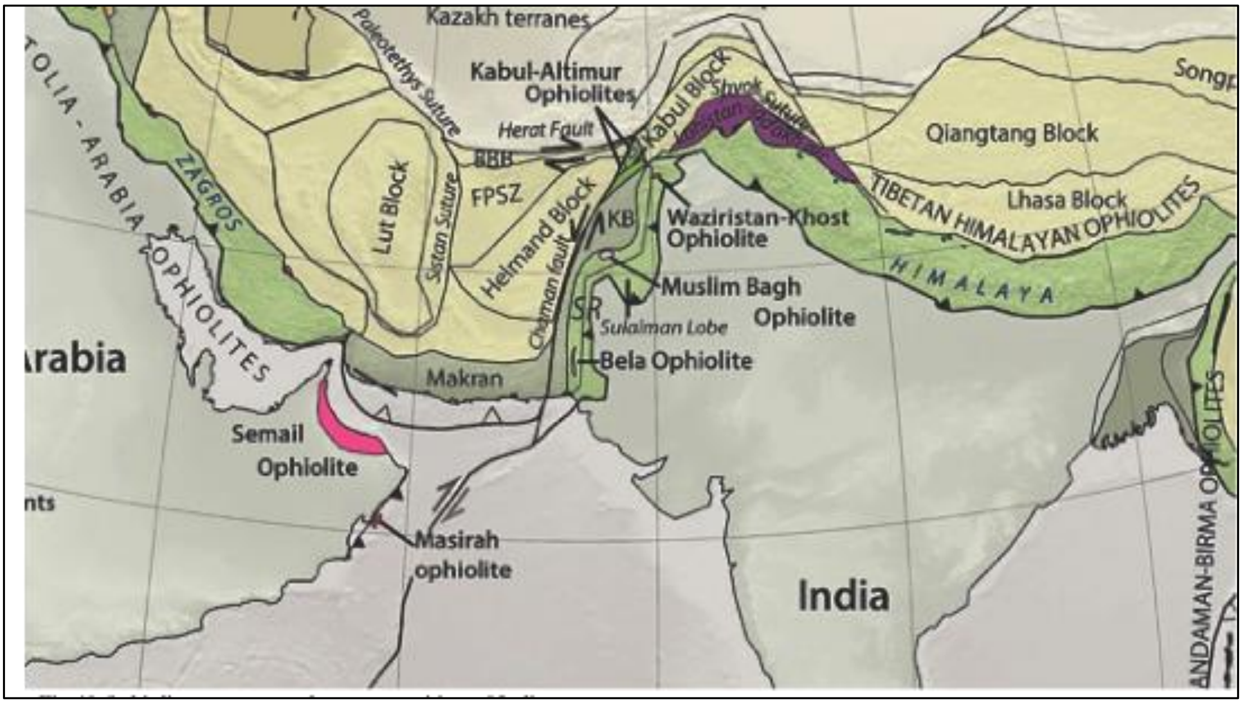


Fig IP3. Ophiolite outcrops and the present position of India

Gaina et al.[22] mention that the first noted anticlockwise movement of India was associated with the initial separation from the Seychelles. This closely coincides with the acceleration in the mid-Cretaceous (93-83 Ma – see Fig IP5) which itself is associated with the heated formation of the Morondava LIP (Madagascar) and with it the lowering of the viscous drag on the NW margin. As such, angular rotation would have started during this period. If this is the case, the oblique convergence with Arabia (Figs IP2a, b & c) can be interpreted as being a consequence of the relative positioning of the moving rotating Indian plate and the combined African and Arabian plates. It is thus very unlikely that the oblique movement would have contributed any force capable of aiding the angular rotation of the Indian plate. However, the oblique movement would have aided the alignment of the Indian plate towards the Eurasian plate

It is also postulated that the angular rotation or final reorientation about NW Greater India to its present position (Fig IP3) would require it to be compressed and trapped to enable the now 'hard' lower part of the Indian plate to act as a pivot point against Eurasia. The compression sequence and its position at present is illustrated in Fig IP4. The sea spreading ridge forces describing CP movement are challenged by the concept of 'sea floor stretching' as set out by Maurer[36].

In all cases the changes in velocity varying from acceleration to deceleration were noted by the different techniques applied.

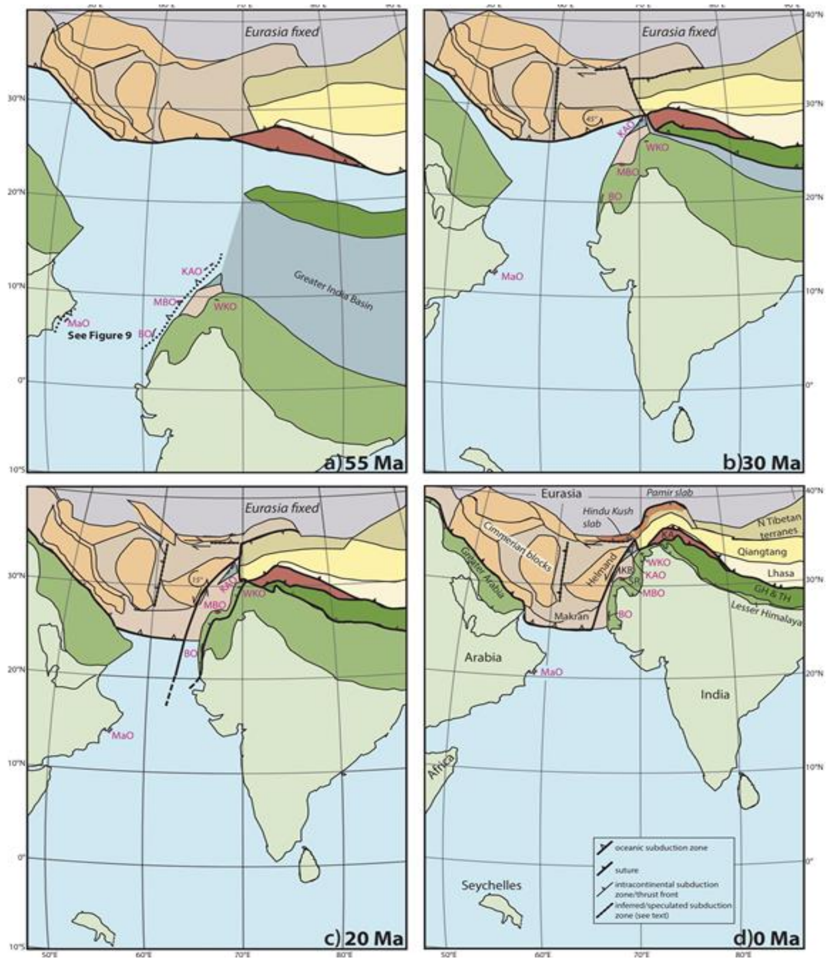


Fig IP4 Compression stages of Greater India, Gaina, van Hinsbergen and Spakman

16.4 Positional reference data used for determining the reasons for the velocity changes

Van Hinsbergen's published papers[71,72] enumerates many of the various arguments put forward by other authors to explain the variation in the rate of convergence (both acceleration and deceleration) of the movement of India towards Eurasia. In his own research Van Hinsbergen set out to examine the following:

- Whether plume head arrival is indeed likely to generate accelerations in Indian-Eurasian convergence
- Whether the total relative rate of plate motion, especially since 65 Ma, can be entirely ascribed to plume head spreading and
- Whether the disappearance of a plume head can generate the 50–35 Ma India-Eurasia deceleration or
- Whether an additional slowing factor (e.g., related to continental subduction) needs to be invoked.

To this end the relative rates of India-Eurasia plate motion were examined by combining the estimated plate motions using marine geophysical data from the Atlantic and Indian oceans. This was followed by examining the numerically simulated changes in plate motion induced by the arrival of a mantle plume, one with and one without viscosity variations. The major points taken into consideration included:

- The influences of mantle plumes and continental collision on rates of India-Eurasia relative plate motion,
- The relative motions of the reference hot spots and the movement of the Euler pole of rotation of the then moving African plate.

For the purposes of this treatise the most important aspect of Van Hinsbergen's work[71] was in comparing the observed plate motions to create a time/velocity reference frame for India's movement.

It is for the above reasons that the author superimposed the pictorial movements of India on a Van Hinsbergen time/velocity/latitude framework with its high input level albeit with some unknowns. This is considered the simplest way to discuss and explain the acceleration and deceleration behaviour of the Indian plate as a function of momentum/viscosity considerations.

16.5 Plotted pivotal velocity against positional points of the moving Indian Plate

Fig IP5, as set out below may be easier to follow by referring to the more detailed information in Sections 16.5.1 and 16.5.2 which provide a chronology of the movement of the Indian plate in context to the ocean basin and other continental plates in the region. The data are based on Seton[58].

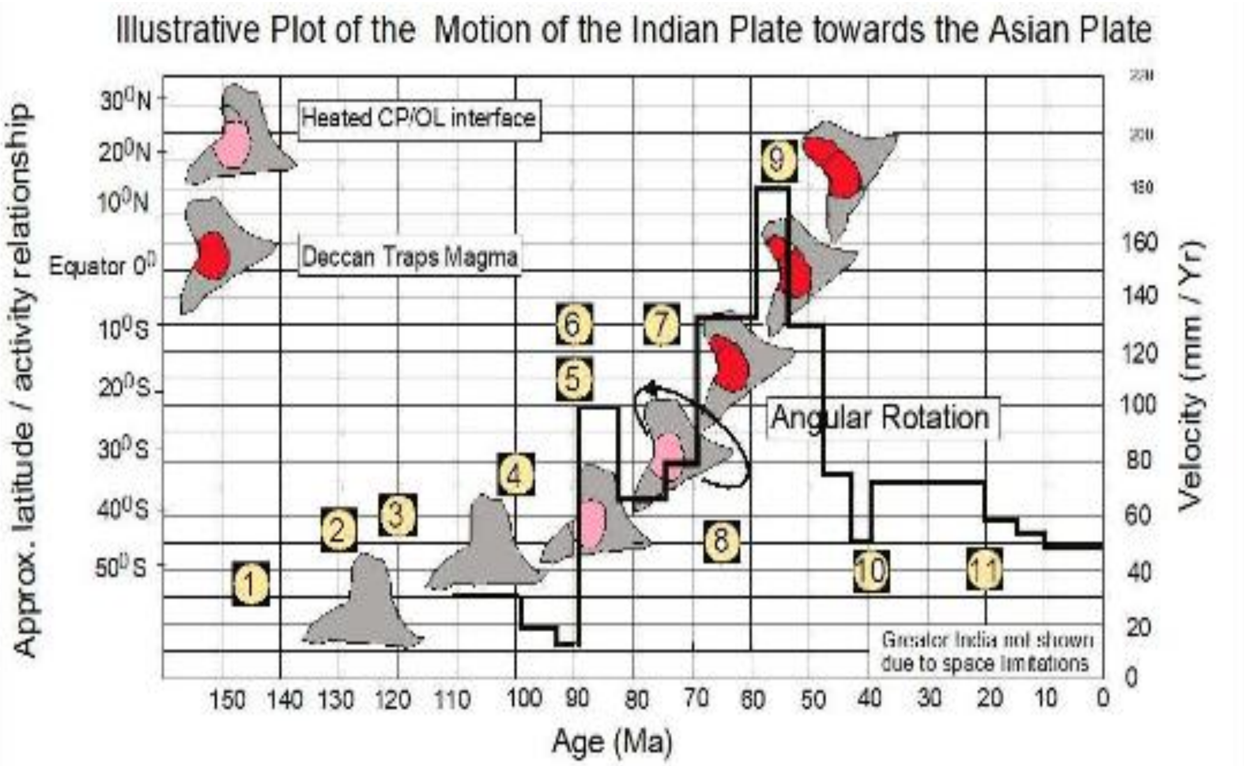


Fig IP5 Plotted pivotal velocity/positional points of the moving Indian Plate. Greater India is not displayed to avoid overcrowding the diagram

Acknowledgement with thanks to Prof D JJ van Hinsbergen for the use the diagrams, extracted from his published papers for illustrative educational purposes.

16.5.1 Historical location data of the Indian Plate

1) 200 Ma: Pangea intact but transform faults exist including between Arabia-India, through E. Africa and S. Africa-Antarctica - i.e., the boundary between E and W Gondwana. Cimmerian terranes separate Paleo & Meso-Tethys Oceans.

2) 180 & 160 Ma: This same transform fault runs from NW India to W Madagascar. Meso-Tethys Ocean subducting under Amuria-Laurasia

3) 170 Ma: Accretion of Cimmerian terranes to the Laurasian southern margin, closing Palaeo-Tethys Ocean (Meso-Tethys to S of Cimmeria). Cimmeria was made up of Iran, Afghanistan, Pakistan, S. Tibet and Sibumasu (Thailand, part of SW China, NW Malaya, NW Sumatra)

4) 160 Ma: Meso-Tethys subducting under Laurasia/Amuria.

16.5.2 Movement history as plotted in Fig IP5 (after van Hinsbergen[71] and Seton[58])

1) 160-140 Ma: India-Madagascar split from Africa during this interval. At 140 Ma India was still joined to Antarctica and Australia and Madagascar was still attached to India. Neo-Tethys forms due to spreading. Most of the Meso-Tethys lithosphere is consumed.

2) 140-120 Ma: India split from Antarctica and Australia during this time. A transform fault developed between India and Madagascar.

3) 120 Ma: Plates carrying India, Antarctica, and Australia with their adjoining parts of oceanic lithosphere were now separate from each other. The Greater Indian plate includes part of the Tethys Ocean.

4) 100 Ma: India and Madagascar still joined but were beginning to split. Antarctica & Australia were still joined.

5) 94-84 Ma: India and Madagascar split. (Gaina 2015). Possible start of the oblique collision with the Arabian plate.

6) 90 Ma: Acceleration of India coincides with the formation of the Morondava Large Igneous Province (LIP) in Madagascar.

7) 84-70 Ma: India is shown to be decelerating and starting to rotate anticlockwise to move more towards NE. Australia and Antarctica are starting to separate by ‘unzipping’ W-E. Oblique collision with the Arabian plate continues.

8) 70-60 Ma: India accelerates. Réunion Plume initiates Deccan volcanism. Anticlockwise rotation of India in its final phase. Neo-Tethys Ocean closing.

9) 55-50 Ma: India crosses the equator and begins to decelerate.

10) 40 Ma: India begins to collide with Eurasia.

11) 20 Ma: Full separation between Australia and Antarctica during the 40-20 Ma interval. Australia moving east below the equator

Present: India-Eurasia collision continues.

16.6 Momentum considerations. Changes in the velocity of the Indian Plate

The compilation of the above chronology and its fit into the van Hinsbergen[71] graphical time / velocity framework is to outline the sequence of events which, it is proposed, is responsible for the acceleration and deceleration periods of the Indian plate. From the above list of events, three significant ones of interest in this discourse are the ways in which both the direction and velocity of the Indian plate were affected:

1. The first being the proximity of the Morondava LIP c. 90 Ma, the heat from which must have affected the CP/asthenosphere interface on the upper western side of the Indian plate.
2. The second being the eruption of the basaltic magma onto about 15% of the Indian land surface creating the Deccan Traps, peaking at c. 66 Ma. This event is related to the Réunion Plume which is still in existence.
3. The third being the so-called ‘deceleration’ of the Indian plate c. 84-70 Ma. The deceleration at c. 50 Ma is probably related to the start of the convergence of the Indian CP with the Eurasia plate.

Despite the reasons for the velocity changes not being universally accepted, these significant events are considered relevant to the understanding of the influence of momentum in the study of tectonic movements.

16.6.1 Acceleration / increase of plate velocity due to lowering of viscous drag

Following on from Sections 9 and 15, it can be assumed that at c.120-100 Ma the Indian-Madagascar plate complex (IMPC) was moving east as a single plate under its own momentum. At c.90 Ma the geological record shows the IMPC beginning to accelerate while splitting apart until separation between India and Madagascar was complete at 84 Ma. This whole period coincides with the Indian plate moving through the vicinity of the plume that generated the Morondava LIP and is also co-incident with the oblique convergence of the Indian and Arabian plates and the emplacement of the Masirah Ophiolite[21].

The heating of the CP/asthenosphere interface at the top western edge of the Indian plate by the Morondava LIP would have resulted in the partial lowering of the coefficient of friction which in turn would have caused the Indian plate to both accelerate and be skewed in an anticlockwise direction towards the NE. As it is not possible for a moving body to change direction or move at a different velocity unless acted on by an external force (Newton's First Law of Motion), viable explanations need be given to explain the sudden (in terms of geological time) change in direction. Thus, while no further momentum or energy can be imparted, the loss of the viscous drag resistance to the velocity of the plate would allow it to accelerate.

16.6.2 Abrupt stop of acceleration and start of the actual or 'apparent deceleration'

At c. 90 Ma the Indian plate which had accelerated to a linear velocity of 100mm/year appeared to stall. This was followed by deceleration to 65mm/year by c. 85-70 Ma. It was during this period (coinciding) with the formation of the Morondava LIP and when southern India was at 45°S), that India began to change its direction of movement from east to north-east. On Fig IP5, the deceleration is plotted as a 'loss of linear velocity' between 83 and 70 Ma.

In the same manner that the acceleration or apparent increase in momentum of a moving body can be explained as being due to the loss of a drag force, the deceleration or apparent loss of momentum may well be explained as one in which the loss of linear velocity or deceleration is accounted for by the increase in the angular velocity of the Indian plate. This is taken together with the possible extra angular distance travelled by the reference the positional reference point.

It may also be argued that as the Indian plate moved away from the oblique convergence position and started to move at a greater velocity (Fig IP5) the oblique encounter may well have had an inhibiting effect on the rate of angular rotation. Prior to the convergence phase a small deceleration at c.100 to 90 Ma was noted [22]. The increase in the heating of the asthenosphere /CP interface and thus the further lowering of the viscosity by the extruding magma during the Deccan volcanism stage would have helped increase the velocity over the 70 to 60 Ma period before the onset of OL-to-OL convergence of India and Eurasia.

16.6.3 Geological activity associated with the rotating Indian Plate

After India and Madagascar separated at c.130 Ma, the Indian plate including Greater India started to turn anticlockwise. It is postulated that this anticlockwise rotation would set up tensile stresses resulting in the initial sea floor stretching (see Section 6) near the area now known as the Mascarene plateau (a submarine plateau in the Indian Ocean NE of Madagascar). The continued movement of the Indian plate formed the oblique NW-SE Carlsberg Ridge with its NE-SW tensile stretch markings as seen on the map shown in Gaina [22,23]. Any evidence of convergence during the journey to Eurasia that was not obliterated by the Deccan magma may well be preserved in the Chagos-Laccadive Ridge (extending south for 25° of latitude from the western India continental margin) and later in the ophiolitic obduction zones between India and Eurasia.

16.6.4 Deccan Traps

During the north-eastward movement of India near the end of the Cretaceous c.66 Ma, lava began to pour out from the mantle onto the continent's surface forming the Deccan Traps that now cover c.15% of the surface. The eruptions were mainly along the western edge of the Indian plate with much of the Traps forming a mountain range now referred to as the Western Ghats. During this period, the Indian plate was passing into the equatorial belt. It is thus possible that the centripetal forces (Fig 18a Section 6) could have stressed the Indian plate when wholly within the equatorial belt creating many N-S extension faults (down to the mantle) through which magma would rise. This tensile stressing may also explain the many N-S trenches in the equatorial belt of the Pacific Basin. The outpouring of lava over several million years would have obliterated the evidence. It is further postulated that the magma would have heated a much larger surface area under the Deccan traps at the CP/mantle level substantially lowering the overall coefficient of friction (μ) between the continental plate and the asthenosphere. The above processes could have helped the Indian plate to move faster towards the Eurasian plate.

16.7 Summary and conclusions

A) The introduction of momentum as the driving force together with the initial selective and almost total final loss of the Greater Indian plate between 80 and 60 Ma would have severely distorted the surrounding upper mantle and could well be responsible for the multiple ridges and subduction zones noted by the authors named above. As such these processes are considered a consequence of the Indian plate rotation and not the cause. Furthermore. this conclusion avoids the difficulty of explaining the Hess model that calls for a 100 Ma-long thermal isolation of the postulated E-N convection currents cutting across the W-E ones moving the Australian plate.

B) As the concept of momentum was applied to the movement of the Indian plate, the collision with the Eurasian plate can be postulated as one in which the kinetic energy ($0.5Mcp^* Vp^2$) of the Indian plate is transferred to the work needed to compress northern Greater India and uplift the Himalayan Mountains.

C) It is also postulated that the reason for noting the 'deceleration' was due to the plotting of the linear velocity and position of the Indian plate with respect to 'fixed' references as detailed above. Under these circumstances the additional latitude-dominated rotational distance travelled during the angular movement could be noted as 'time lost' with respect to the linear movement. It is thus possible that it is this omission that may well be the basis of the observed 'apparent deceleration'.

17. Case Study 2: Investigation of the Forces Responsible for the Earthquake in Japan 11 March 2011

Information received 18 July 2020. Japan trench (two diagrams) of faults & video showing the 11 March 2011, earthquake. The technical information given by Professor Dr Shigeyuki Suzuki is gratefully acknowledged.

17.1 Introduction

This preliminary investigation resulted from the observation that the fault scarps off Japan (Fig JE1) face eastwards towards the Pacific thus suggesting that the Continental Plate (CP) was driven or forced over the Oceanic Lithosphere (OL) as distinct from the OL subducting under the CP. As the movements and thus the forces relating to the earthquake on 11 March 2011 were closely measured and monitored before, during and after the earthquake on the four main islands of Japan it seemed reasonable to use this information. (The earthquake sequence can be viewed on video in Appendix 8 at https://www.tectonic-forces.org/index/a-8-japanese-earthquake). Fig JE 2 is a screenshot from the video.)

In view of the observed differences in rotation and forward distances travelled by the four islands, it appeared that solutions based on differential rates of subduction would give complicated answers. It was therefore decided to ascertain if the circumferential tensile forces in the Earth's rim which are related to the rotational velocity of the earth (Maurer[36]) could yield a viable explanation.

The sketches shown below with the explanations of the fault scarps off Japan where it faces eastwards towards the Pacific Ocean helps give credence to the proposition that the continental plate (CP) is driven over the Pacific oceanic lithosphere (OL) as distinct from subduction of the OL under the CP. The video shows the individual directional movements of the four main islands immediately before, during and after the earthquake.

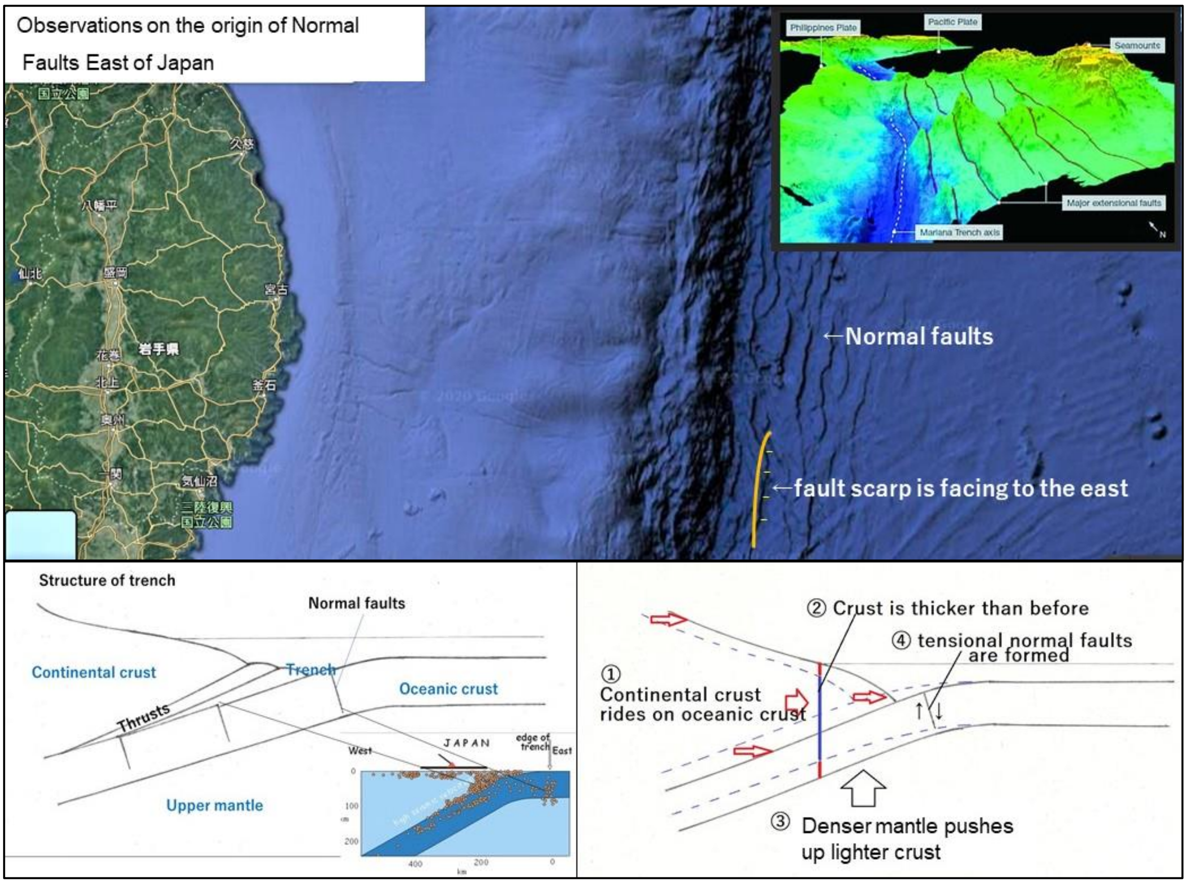


Fig JE1 Observations on the origin of normal faults east of Japan

17.2 Earthquake movement sequence

At present the Atlantic Ocean is expanding at the expense of the Pacific Ocean into which the American plates are moving from the east and the Eurasian plate is moving in from the west. The ingress of the eastwards moving anti-clockwise rotating Australian plate may also be adding to the magnitude of compression. The latitude-aligned Aleutian trench fracture in the northern Pacific is presently explained as being due to the subduction of the Pacific plate under the North American plate.

The still below (Fig JE2), from the aforementioned video, displays the movement of the directional force arrows, red towards the east and blue towards the west, at the exact time of the earthquake. Prior to the earthquake (as seen in the video) the displacement arrows across the Japanese chain from Hokkaido down to Kyushu pointed northwest. However, to the south along the Okinawa trough, the displacement arrows pointed southeast. The area in question stated as being approximately 300 km long by 150 km wide lurched 50 metres to the east-south-east and was thrust upward about 10 metres.

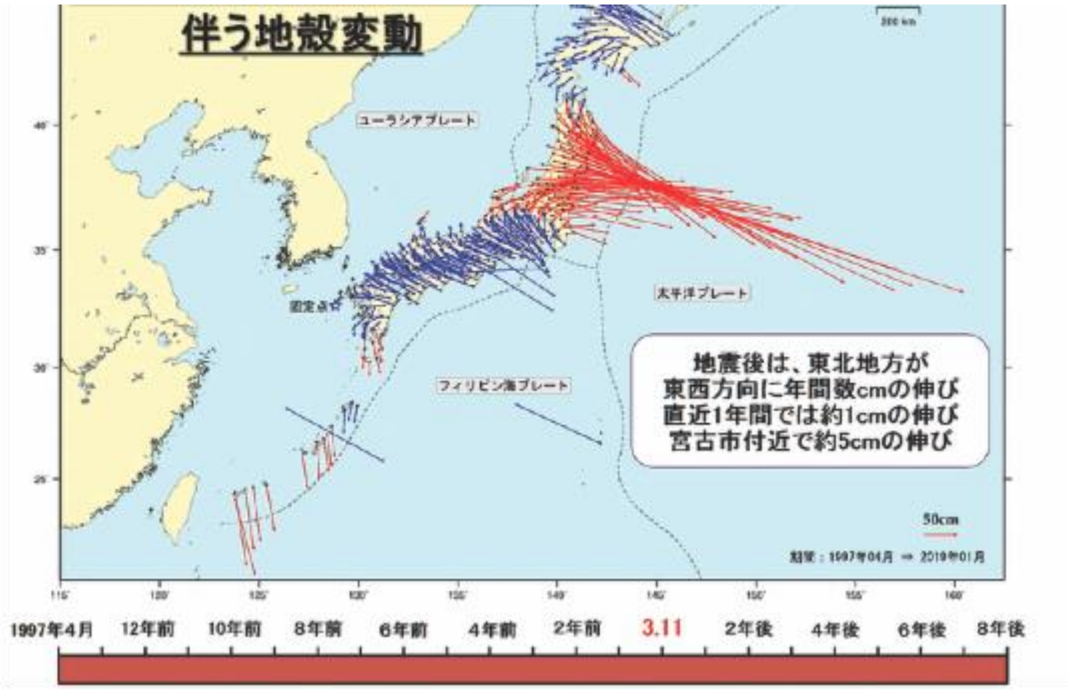


Fig JE2 Screenshot showing the sudden movements during the earthquake of 2011

Just prior to the earthquake, the change in the direction of the displacement arrows to an anticlockwise movement is first noted on Hokkaido at position '8 (RHS of 3.11)'. At '6 (RHS of 3.11)' the displacement arrows at Kyushu start to turn clockwise. At this juncture both ends of Japan appear to be taking on an 'S' shape. At position '2.5 (LHS of 3.11)' the southern two main islands of the Japanese plate are starting to turn clockwise in opposition to the anti-clockwise movement of Hokkaido. The above-mentioned movements at both ends of the Japanese arc put Honshu under a severe bending moment which resulted in the fracture in the direction of the bend and the sudden eastward outward movement of a segment of Honshu (Fig JE3).

This action is like that of the breaking of a cane as it is bent into a hoop. The most probable explanation (as shown below) is that while the Japanese arc was being pushed eastwards, Honshu island appears to move at a slightly higher velocity. As Honshu with its fault line is moved forward the adjacent islands will turn inwards, the Kyushu (southern) end turning clockwise and the Hokkaido (northern) end anticlockwise. In an engineering application, this would be the stress pattern when sheet steel is deformed by folding or being punched into a deep 'U' shape such as a basin.

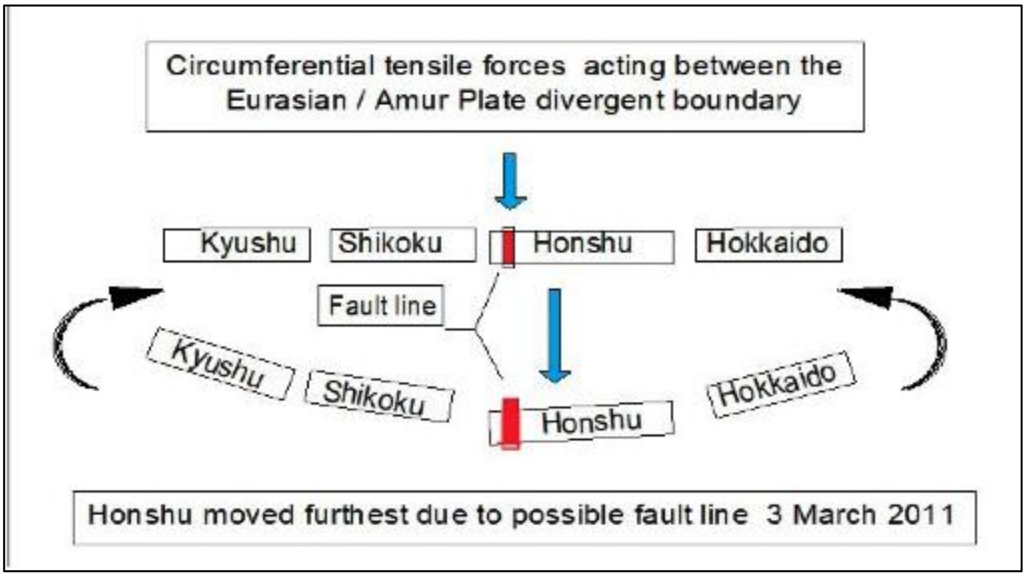


Fig JE 3 The possible representation of the eastward push of Japan

Fig JE-4i

Fig JE 4 Map showing the epicentre and zones of perceived shaking

17.3 Brief literature survey on the evolution of the Japanese and Eurasian plates

As subduction by the Pacific basin under Japan was not considered as the only or even the prime cause of the earthquakes on the mainland, it was decided to investigate the possibility that faulting within the Eurasian plate may have a greater effect than hitherto anticipated. As such it was decided to first investigate the historical makeup of Laurasia to look for areas of possible crustal weakness.

Laurasia was the combination of Laurentia and Eurasia during the Carboniferous. During that period, Eurasia comprised Baltica, Siberia, Kazakhstania and N & S China and peri-Gondwanan microcontinental blocks. Previously, in the Devonian, Laurentia was combined with just Baltica and the peri-Gondwanan blocks as Laurussia.

Siberia, Kazakhstania and the Chinese blocks were still separate at that time. In the late Carboniferous, Gondwana amalgamated with Laurasia to become Pangea. Laurasia split into North America (including Greenland) and Eurasia when the North Atlantic opened from the late Cretaceous into the Paleogene (about 80 Ma onwards). The Central and South Atlantic were well developed by this time.

At the start of the Miocene (23 Ma), Japan was part of Eurasia. By 15 Ma, as the Sea of Japan opened, Japan was pivoting away from China but still attached to it (as a peninsula) at the southern end. This end of Japan (Kyushu) separated from China in the late Pliocene. Hokkaido was uplifted from below sea level. For Japan to move (or pivot) away from Eurasia it must have been moving at a faster rate relative to the whole Eurasian plate (researched by Allan Wheeler).

At present, the northern island of Hokkaido and northern Honshu are on the Okhotsk plate; southern Honshu, Shikoku and most of Kyushu are on the Amur plate (a sub-plate of Eurasia). Northern Honshu and Hokkaido are bounded by the Pacific plate to the east and southern Honshu and the southern islands are bounded by the Amur plate to the west and the Philippine Sea plate to the east, which is in turn bounded on the east by the Pacific plate. The plate boundary between Amur and the Okhotsk plates cuts through the central part of Honshu Island.

The boundaries between the North American and Okhotsk plates are now deemed to be separated by a strike slip fault. The exact position of the plate boundary between the Eurasian and Amur plates has still to be agreed.

17.4 The rifts in the Eurasian plate that are possibly associated with the 2011 Earthquake

Despite various theories/claims including one that cites the slippery clay lining at the fault boundary was the cause of the earthquake, the change in the direction of the displacement markers as noted on the video shows that significant forces are needed to twist an island chain like Japan.

As such several alternative possibilities need to be considered.

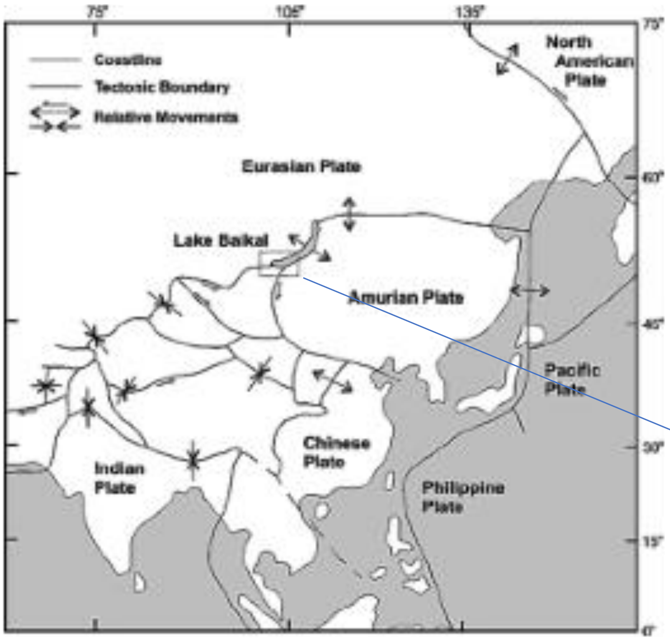


Fig JE5a Regional map showing the location of the Baikal Rift Zone in southern Siberia and the associated lithosphere plates and microplates that compose the tectonic framework of central Asia.

The dashed square marks the study area of the BEST project. After Zoneshain and Savostin (1981) and Moore et al (1997)

The late Cenozoic Baikal Rift Zone (BRZ) in southern Siberia is composed of several individual topographic depressions and half grabens with the deep Lake Baikal at its centre. A 350 km section of the 2,000 km long feature has been interpreted as resulting from mafic intrusions. It is also suggested that the BRZ is formed by passive rifting in the rheologically weak suture between the Siberian Zone and the Amur sub-plate.

The BRZ is one of the four major Cenozoic continental rift systems, and it shows most of the characteristics associated with continental rifting: elongated sedimentary grabens, elevated margins, volcanic provinces, normal faults, and high seismic activity. The BRZ one of the most seismically active continental rifts in the world.

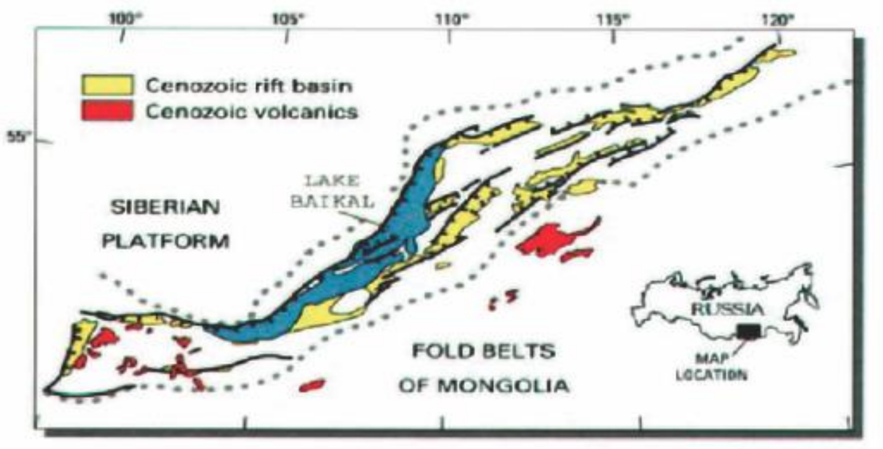


Fig JE5b Map showing the location of Lake Baikal and associated rift basins

It is also suggested that Intracontinental rifting is assumed to be the initial stage of a development, that eventually may lead to breakup and separation of lithospheric plates and formation of new oceanic plates. Should the extension cease, there would be a change to the formation of wide sedimentary depressions or grabens [Turcotte and Emerman,1983; Olsen and Morgan ,1995]. Although this feature is 2,000 km from the Okhotsk plate it is nevertheless in contact with the intermediate Amur plate. More importantly extension rifts which are not a function of subduction are evident along the Eurasian plate from Iran to China and the New Madrid Seismic Zone in the USA.

17.5 Earthquakes along the Silk Road – reinterpreting the historic and prehistoric ruptures of central Asia

In contrast to plate boundaries, where earthquake hazards are usually confined to narrow zones around ocean margins, active faulting within continental interiors is spread across very wide areas, and with intervals of hundreds, or even thousands of years between large earthquakes in any one area. The long recurrence intervals in continental interiors poses challenges for the identification of active faults both ancient and modern, across the interior of Asia. The study would need to encompass a region spanning from Iran in the west, through the former Soviet Central Asian republics, to China in the east. Many of the large late-historical examples are from the Tien Shan region of central Asia, as represented by the cluster of earthquakes in 1887, 1889, and 1911 in the vicinity of Almaty, Kazakhstan. Attempts to use the above examples to address the relationship between rupture length and amount of slip, including the potential for large earthquakes to occur due to complex rupture zones across multiple short faults is made difficult as the prominent faults of central Asia have no documented historical record of earthquakes near them. This is despite the display of evidence in the landscape showing ruptures in the recent past.

17.6 Development of stress faulting and continental plate elongation by centripetal forces

In the same way that the Atlantic Ocean basin is growing at the expense of the Pacific basin by the westward movement of the American plates, the Indian Ocean is also growing at the expense of the Pacific Ocean by the slower eastward movement of the Eurasian plate. In its eastwards movement the Eurasian plate moves along a tortuous elongated area between latitudes 15° and 60° N This could involve the stretching of the fluid viscous mantle into a thinner but nevertheless continuous section and the cracking of the brittle oceanic layers (Fig JE6). Eurasia is known for its many such faults and volcanically active regions.

Although the distances involved with these faults and their extensions are small, the total integrated extension may in fact be of significant proportions to push against the Japanese and Philippine Island arcs on the Pacific side of the Eurasian plate. The frictional resistance offered by the forcing down of the oceanic lithosphere (OL) would put the converging margins under compression with the resultant cracking perpendicular to the line of force. If the cracking extends down into the mantle, then magma will issue forth as volcanoes. Ultimately it is postulated that the OL underlying the Sea of Japan would absorb any elongation by rifting caused by the geometric changes of the Eurasian Plate.

17.7 Possible force exerted on Honshu by rollback (Heuret and Lallemand 2005)

The Japan sea basin could also be extended by the slab rollback mechanism. This extension occurs where a denser older slab begins to sink relative to the overlying plate as shown below in Fig JE7. Heuret and Lallemand (2005) show several variations which would result in back arc extension and rifting. The illustration shown is based on their work. As the stress patterns from rollback are very unlikely to produce the inward facing curving force patterns as seen on the video, this aspect is not being pursued.

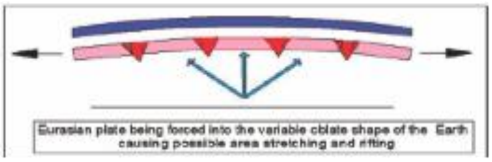


Fig JE6 Eurasian plate being forced into the variable oblate shape of the Earth, causing possible area stretching and rifting.

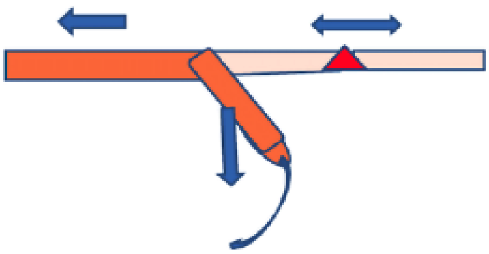


Fig JE7 Effect of slab rollback. After Heuret and Lallemand (2005)

17.8 Differential circumferential tensile stress (DCTS) in the Earth's rim

The calculated DCTS induced in the Earth's rim has sufficient force to cause the break-up of a supercontinent such as Pangea and detached plates such as the westward-moving American plates and the eastward-moving Eurasian plate migrate away. In a similar manner, the circumferential stress will separate a peninsula block from the main plate by exploiting of any weakness in the oceanic lithosphere and the upper mantle. This action would be felt all along the western edge of the Japanese island arc which would be pushed eastwards and which in turn will cause stress faulting in the underlying oceanic lithosphere. A similar situation is observed in the Philippines.

At present the geological structure and composition of the islands are not fully mapped and understood. A major complication in understanding the make-up is occasioned by the islands being formed at different times and thus having different ages. Furthermore, the younger plates with greater volcanic activity appear to face the oceanic basin while the sides facing the Sea of Japan show evidence of heavy faulting and sedimentation. The presence of thick Quaternary accretionary deposits inhibits the study of the complete make-up of the Japanese Island system, but gravitational anomaly mapping, seismic surveys and borehole evidence will in time yield a better understanding of this complex system.

However, it is this very make up that allows a constant force applied to the whole western side of Japan to preferentially move the weakest parts the greatest distance. This process is likely to continue until such time as the Island system is either completely broken up or welded into a unitary configuration. The question arises whether the islands are connected at depth or are independent terranes. Furthermore, were the islands connected when the sea level was up to 120m lower during the Quaternary ice ages? Under these conditions the associated push force would be sufficient to force the Japanese island eastwards. The circumferential forces would meet little frictional resistance at the Izu Collision Zone from where the Honshu Island could lurch forward thus triggering the earthquake of March 2011.

17.9 Discussion and conclusions

The absence of similar detailed knowledge of other major earthquakes both along the convergent margins and along the central Asian complex on the Eurasian plate makes it difficult to offer general conclusions regarding the forces responsible for earthquake activity. It is also difficult to reconcile what appears to be a variable direction subduction process of the oceanic plates as being solely responsible for all the earthquake and volcanic activity along the Pacific basin rim. The geology of this area, which is generally referred to as the 'Ring of Fire', is complex and the conclusions and discussion points offered are thus limited in scope and subject to correction.

The first indication that the continental crust is moving over the oceanic crust is given by the eastward facing scarps of the Japanese arc. Using this as the starting point, various tectonic processes were investigated to determine their contribution to this situation:

i. The eastward movement of Eurasia: the variable shaping of the Eurasian plate by extension or compression as it is being pushed eastwards by its passage through different diametral surface areas of the bulge is unlikely to be translated as a physical push force against the Japanese arc. The oceanic crust of the intermediate Sea of Japan would most likely absorb the limited preferential extension by possibly buckling and cracking and possibly give rise to magma intrusion. However, this action of stretching and/or compression may be considered as a prime force for the opening of the Baikal and other rifts on the central Eurasian plate.

ii. Possible extensions of the Sea of Japan by rollback.

iii. The faults induced in the subducted OL whilst being forced under the CP can obviously lead to slab segments breaking away and causing rollback. The absence of detailed information limits the discussion on this point. Collaborative evidence is needed to pursue this line of discussion.

iv. Circumferential rim forces: the above-mentioned video suggests the earthquake occurred 'after a sustained 14-year application of an eastward 'push' force over the whole of Japan'. This finally caused the weakest-held section Honshu to move the furthest eastwards.

Historically, Japan, which was part of Eurasia, pivoted away from China at the southern end as a peninsula and the Sea of Japan opened at c. 15 Ma. Kyushu separated from China in the late Pliocene. Hokkaido was uplifted from below sea level. It is thus feasible that the circumferential forces treated this Japanese section as a separate entity and, being smaller, it was able to respond by moving at a slightly faster rate than the main Eurasian plate. This point is partly speculative and open to argument as the variable speed movement would need to be accompanied by a simultaneous variable speed subduction process in the same direction. However, a unidirectional circumferential driving force will move objects at different rates depending on the frictional resistance. Bearing in mind the continuous westward movement of the American plates and the continuing eastwards albeit slow movement of Eurasia with its fault lines that cannot be attributed to subduction, the most likely force triggering the earthquake will be the circumferential tensile forces.

The sketches in Fig JE1 above with the explanations of the fault scarps off Japan where they face east towards the Pacific Ocean help give credence to the proposition that the continental plate (CP) is driven over the Pacific oceanic lithosphere (OL) as distinct from subduction of the OL under the CP. The video described above shows the individual directional movements of the four major Japanese Islands immediately before, during and after the earthquake.

Appendix 1 Consideration of the Rotational Behaviour of the Sun and Planets

Table 1 Planet Data – Source NASA

Planet	Density (kg/m3)	Equatorial Diameter (km)	Distance from Sun (Million km)	Length of Day (hrs)	Orbital Period (Earth days)	Orbital Velocity (km/s)
Mercury	5,427	4,879	57.9	1,407.5	88.0	47.4
Venus	5,243	12,104	108.2	5,832.4	224.5	35.0
Earth	5,513	12,756	149.6	23.93	365.2	29.8
Mars	3,934	6,779	227.9	24.6	687.0	24.1
Jupiter	1,326	139,822	778.3	9.9	4,330	13.1
Saturn	687	116,464	1,426.7	10.7	10,748	9.6
Uranus	1,270	50,724	2,870.7	17.2	30,666	6.8
Neptune	1,638	49,244	4,498.4	16.1	60,149	5.4
Data: NASA General Info						

It is noted that apart from Venus and Uranus all the planets rotate in the same anti-clockwise direction as does the Sun[35]. Table 1 also shows that despite the wide range of planet diameters, their rotation period is within a 10–24-hour envelope (except for Mercury and Venus). This immediately suggests that the rotational velocity is controlled by the rotation of the Sun. The inner core of the Sun is reportedly rotating on its axis once every 5 Earth days[35]. However, as the Sun itself displays a measurable 'wobble' (Fig A3) as measured between 1944 and 2020 different scenarios can be contemplated. The first scenario is that the wobble is linked to the variable gravitational pull from all the planets as they move around the Sun in their elliptical orbits as shown in Fig A1.

Fig A2[36] shows that the Sun's own COM is continuously and cyclically offset from its axis of rotation.

The second scenario is to give consideration of the possibility that the Sun itself may have a faster rotating inner layer of the core with an approximate 24-hour rotation velocity mode. If this prediction can be postulated, then the concept of a 'gravitational crank coupling' (GCC) is worth consideration. Under these circumstances a nominal 1:1 daily rotational ratio between the Sun and the Planets does not seem that far-fetched. The gravitational effects of the moons on the various Planets are not considered here.

Mercury with its almost zero tilt and extremely low daily rotational velocity suggests that the COM is almost coincident with the N-S rotational axis making it more likely to be 'pulled' around in orbit, rather than be rotated around an axis. The higher orbital velocity of Venus than the Earth, causes it to overtake the Earth as they orbit the Sun. Furthermore, Venus's inclined orbital path causes the planet to move above and below the Earth's orbital path. It is outside the remit of this research programme to find a resultant gravitational pull from the Sun and Earth that explains the slow retrograde rotation of what appears at first sight to be an 'upside down' planet given its axial tilt of 177.3°. Venus may have been inverted by a collision. The North Pole is at the bottom so viewing from 'above' that, its rotation is still anticlockwise. Uranus' axis at 97° may also be due to a collision – both events early in the life of the Solar System.

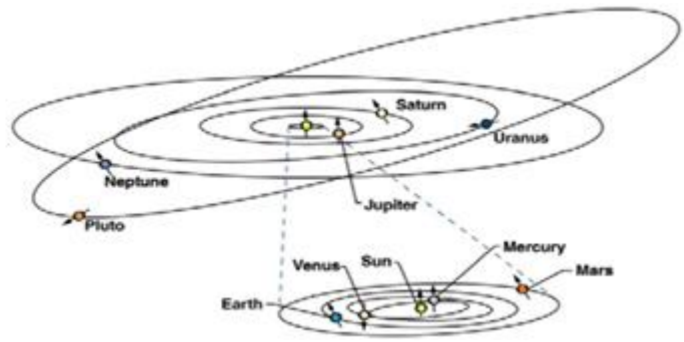


Fig A1: The planets' orbits around the Sun.

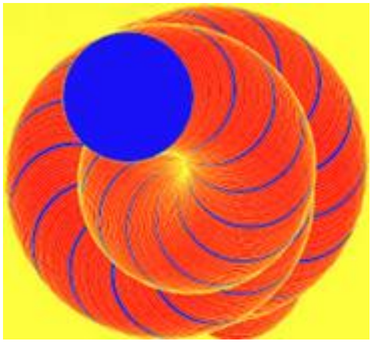


Fig A2: Offset of the Sun's COM

Appendix 2 Caltech and the Earthbyte Project

Use of Equation 2 relating the circumferential stress to the Radius of Eccentricity

Title of publication – An analysis of the effects of Angular Momentum and Tectonic Plate Movement

Abstract: The Earth's centre of gravity is dynamic, and its location varies based on exertions of mass on the crust on behalf of continental plates. However minute, these shifts over a long enough period of time have significant influence on periodic axial rotation, convection cell dynamics, and continental rotation. This investigation considers several dimensions influenced by dynamic changes in rotation, angular momentum and gravitational influence using mathematical modelling of the Earth's rotation using a Euler-Liouville formula as described by Akulenko[1]. In 2008, the variations in the Earth's periodicity of acceleration by the application of a Morlet wavelet transform was proposed by Duhau[13]. A geographic information system with raster data visualization capabilities and plate tectonic reconstruction software was developed by an international team from the Earthbyte Project, the Geological and Planetary Sciences Division at Caltech, and the Centre for Geodynamics at the Norwegian Geological Survey. A modified form of the equation for the centre of mass of an oscillating sphere was used by Maurer (2001)[36].

The results of this modelling show that seismic activity and tectonic activity increase with fluctuating periods of acceleration in the Earth's rotational velocity, and that the aggregation of plates has a significant impact on the Earth's centre of mass. This confirms the hypothesis that gradual changes in the Earth's rotational axis and velocity, largely ignored in plate tectonics, have a significant impact on seismic events and tectonic movement. (Fig A3 & Table 2)

This difference in localized mass, calculated as being, effectively, a change in crustal depth and area, may be enough to cause a shift in the Earth's center of mass, and thus on its rotational dynamics. By adopting the formula used by R. Maurer (Maurer, 2001) for the angular momentum of tectonic plates and solving it for the eccentricity of the center of mass, we can then discern the fluctuations in such eccentricity.

$$F = \frac{M\, r\, E\, \pi\, w^2}{4}$$

$$\frac{4F}{M\, r\, \pi\, w^2} = E$$

Where M is the mass of the object, F is the centrifugal force in newtons, r is the radius in km, w is the rotational velocity of the Earth represented in radian form, and E is the eccentricity of the center of mass. If we consider these formulas acting with any amount of centrifugal force in the system, a significant difference in eccentricity results from even minor changes in mass (Table 2).

Fig 34

Fig. A3: Possible causes of the movement of the Earth's centre of mass

Angular Momentum and Plate Tectonics 15

Density (g/m^3)	Centrifugal Force Tested (N)	Eccentricity (km)
2.76	10	0.001185
2.78	10	0.001195
2.76	100	0.011846
2.78	100	0.01195
2.76	1000	0.118462
2.78	1000	0.119503
2.76	10000	1.184621
2.78	10000	1.195033

Table 2: This table illustrates that changes in effective density of even just .879% generate significant changes in eccentricity

Table 2 CALTEC-Earthbyte Project used Equation 2 to derive this table

Appendix 3 Estimation of the Magnitude of the Circumferential Forces Driving Tectonic Movements

This material is reproduced from the main text to aid study.

The mathematical analysis is based on the concept of the outer rim being allowed to slide relative to the main rotating body (Figs A4, A5 & A8).

To determine the forces postulated as being responsible for tectonic movement, the model used is one in which the thin crust can slide relative to the solid body at the crust /mantle interface. By way of illustration, Fig A6 Model A shows that if an unbalanced disc with an outer annular ring containing fluid is rotated about its principal axis, the fluid will move to the 'lighter' side. Fig. A6 Model B shows an analogous situation with the sliding continental plates.

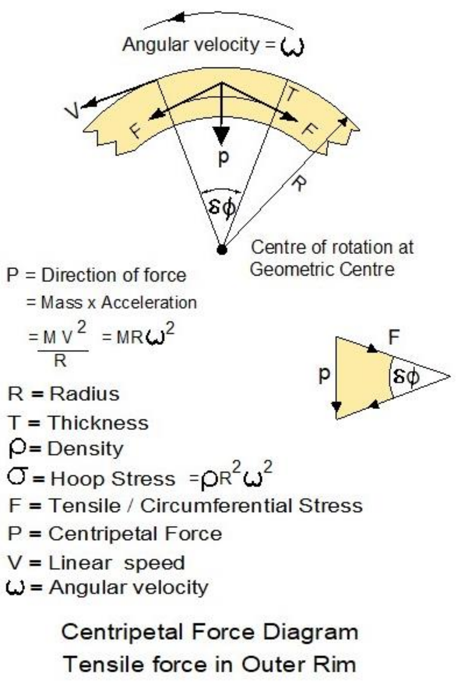


Fig A4. Centripetal force diagram – tensile force in the outer rim

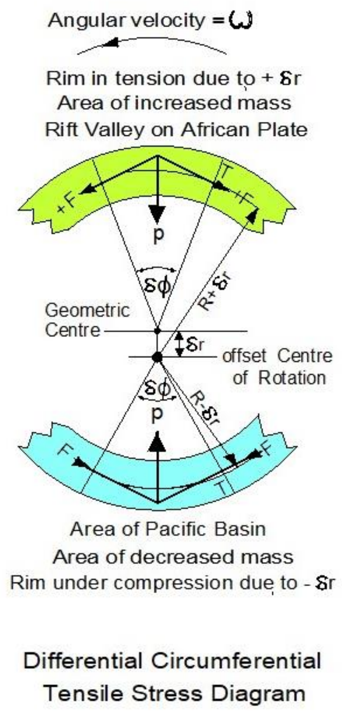


Fig A5. Differential circumferential tensile stress diagram

If we consider the crust as being able to move relative to the mantle, albeit it over a long geological time span, then a simple force diagram (Fig A5 & A8) can be constructed by making the following assumptions:

(a) the crust is a thin shell that can slide relative to the mantle,

(b) the forces owing to eccentricity are superimposed on the stress caused by the general rotation and gravity, and

(c) 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 shell moving relative to the mantle, it is possible to consider what 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 which follow are based on the consideration of the eccentrically induced loads on the thin crust.

In calculating the effects of the circumferential tensile forces (F) at the surface of the earth due to the centre of mass being offset from the principal axis of rotation, the term ‘radius of eccentricity’ (E) is introduced to denote the magnitude of the offset.

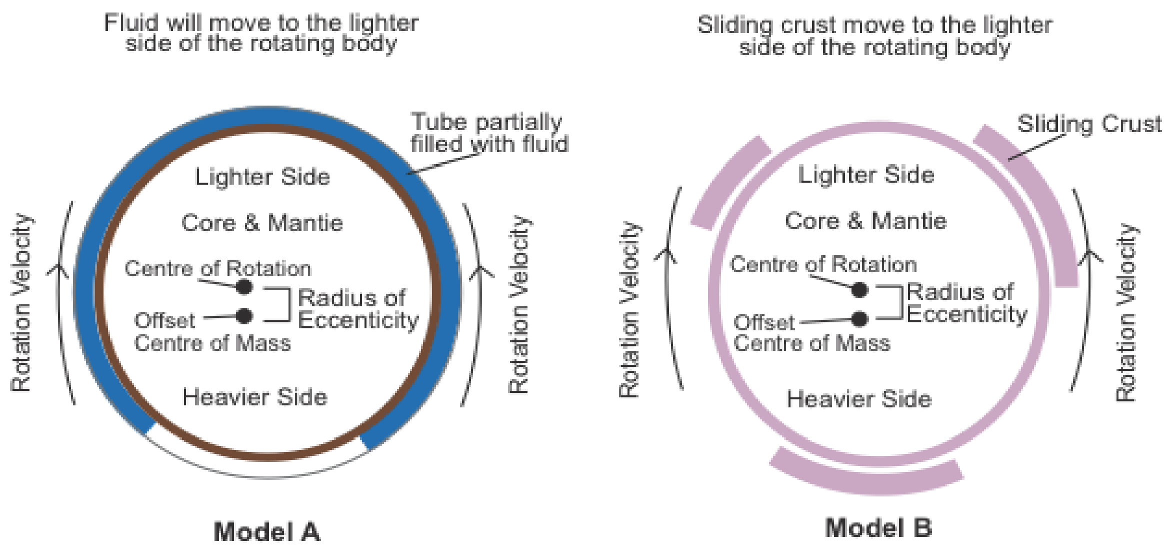


Fig A6: Models used for the calculation of the differential circumferential stress forces required to move the crust to the mantle. The movement to the lighter side is independent of the hard rotation.

The magnitude of the derived circumferential stress (F) will be 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 shell cut across the Earth’s diameter at the Mid-Atlantic Ridge (Fig A7 below).

The force tending to cause 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. Fig C in Fig A7 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 $\pi/2$.

‘Fig C’ in Fig A7 shows the force and vector diagrams used to determine the magnitude of the circumferential stress in the direction of the maximum effective radius. For ease of understanding the force diagram is superimposed on the major geological features on the equatorial belt.

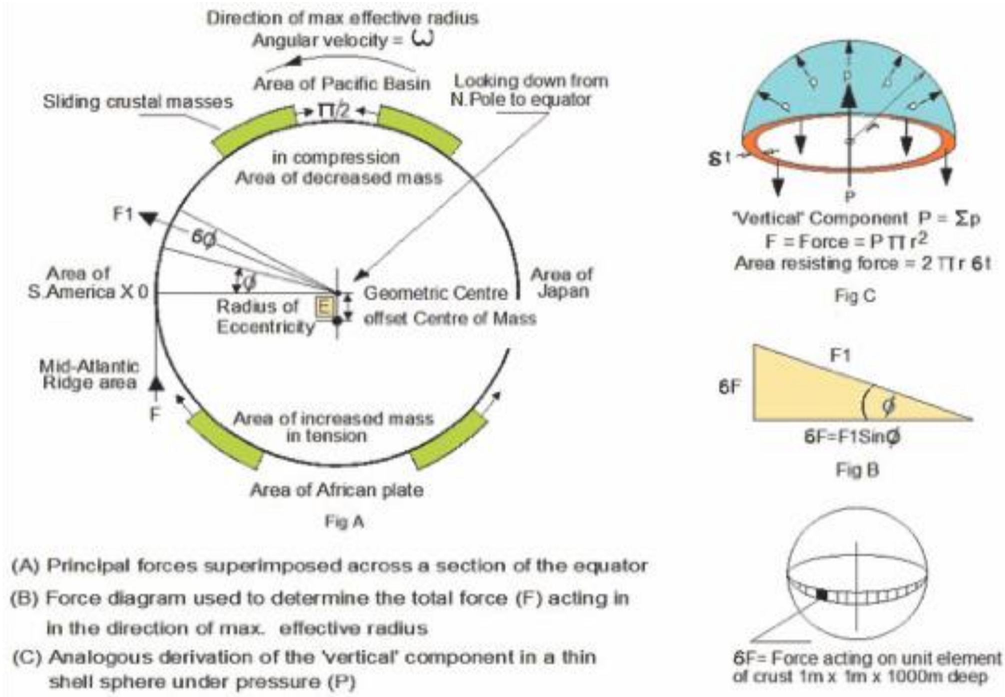


Fig A7: Force and vector diagrams used to determine the magnitude of the circumferential stress in the direction of the maximum effective radius.

Notation	Value
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	1.0×10^3 metres
ω = Angular velocity	7.27×10^{-5} rad s^{-1}
θ = Angle (rad)	
Δe = Effective eccentricity at angle θ	
F = Total force (N) at point X - cf. Fig.11	
F_1 = Radial force due to eccentricity at θ	

Then from the 'force vector diagram' at surface at an angle θ:

Vertical component of F1: $\delta f = F_1 \sin\theta$
Effective eccentricity at angle θ: $\delta e = E\, s\, in\theta$
And mass of segment: $R\,\delta\theta = M\,R\,\delta\theta.$

Thus $F_1 = M\,R\,\delta\theta\,\omega^2 E\sin\theta = M\,R\,\omega^2 E\sin\theta\,\delta\theta$
The vertical force component: $\delta f = F_1 \sin\theta$

$$= M\,R\,\omega^2 E\sin\theta\sin\theta\,\delta\theta$$

$$= \mathbf{M\,R\,\omega^2 E\sin^2\theta\,\delta\theta} \qquad \textbf{(Equation 1)}$$

Thus, the total vertical force

$$F = \int_0^{\pi/2} M\,R\,\omega^2 E\sin^2\theta\,d\theta$$

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

$$= M.R.\omega^2.E\,(\pi/4 - ¼.0) - (½.0 - ¼.0)$$

$$\mathbf{F = M\,R\,\omega 2\,E\,\pi/4} \qquad \textbf{(Equation 2)}$$

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.

With an average density of 2.8 x10^3 kgm^{-3} for a 1,000 m column of section 1 metre x 1metre:

The mass per unit area of crust (m^2) = 1,000 x 1 x 1 x 2.8 x10^3 = 2.8 x 10^6 kg:
The radius of the Earth, R = 6,400 km
The angular velocity of the Earth[55] at the equator (ω) = 7.27 x10^{-5} rad s^{-1}

The radius of eccentricity at the core (E) =1 km.

Hence substituting into equation 2 we have

$F = 2.8 \times 10^6 \times 6.4 \times 10^6 \times (7.27 \times 10^{-5})^2 \times 10^3 \times \pi/4 = 7.44 \times 10^7$ 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 is = 7.44×10^{-2} N m^{-2}, 0.734 Bar or c. 10.79 lb.in^{-2}

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. A9 is used for this analysis. Fig A10 shows the relationship between the Radius of Eccentricity and the circumferential stresses. Fig A11 shows the relationship between F, E and μ.

As above:

the mass of the segment $R\,\delta\theta$	=	$M R\,\delta\theta$
the radial force F	=	Mass $R\,\omega^2$
	=	$(M R\,\delta\theta) R\,\omega^2 = M\,\omega^2 R^2\,\delta\theta$
Thus δf	=	$M\,\omega^2 R^2 \sin\theta\,\delta\theta$

With reference to Fig. 35:

$R = R_0 + E\sin\theta.$

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

which approximates to $\delta f = M\,\omega^2 (R_0^2 + 2E\,R_0 \sin\theta) \sin\theta\,\delta\theta$

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

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

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

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

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

$= \mathbf{M R_0\,\omega^2\, 2\, E\sin^2\theta\,\delta\theta}$ **(Equation 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 (Figs A8 below and A7 above) is considered valid for determining Equation 2 by integrating between 0 and π/2.

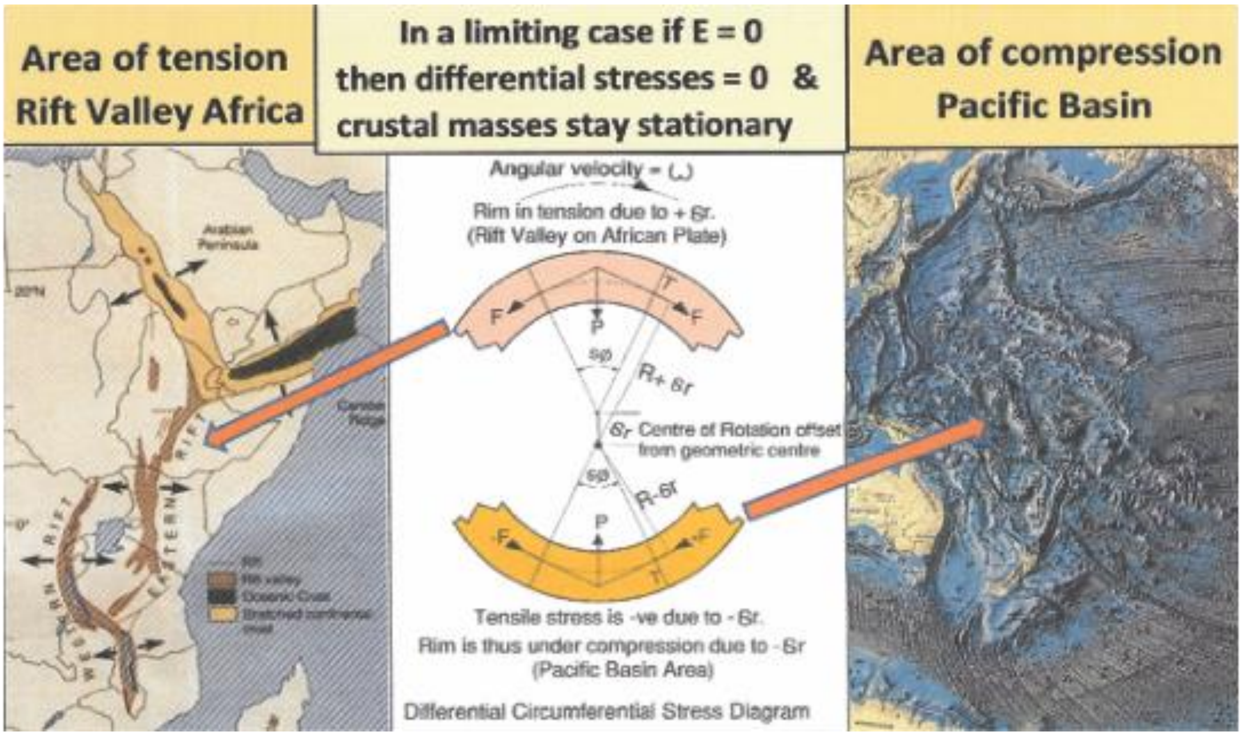


Fig A8: Earth examples of differential tensile stress.

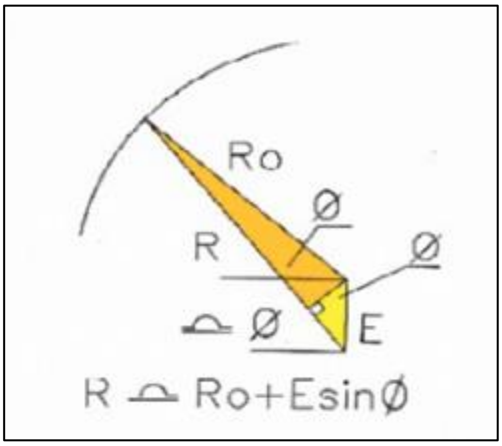


Fig A9: Expression of the forces in the direction of the maximum effective radius

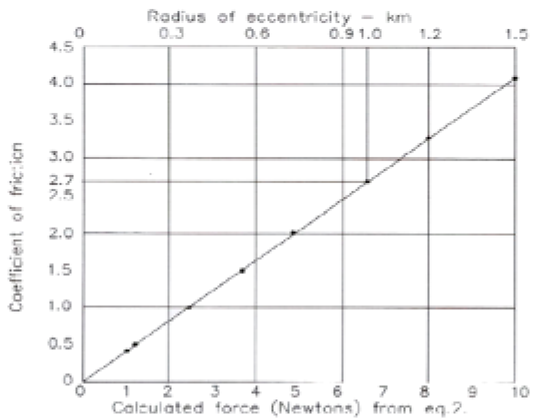


Fig A10: Relationship between the radius of eccentricity of the circumferential stresses.

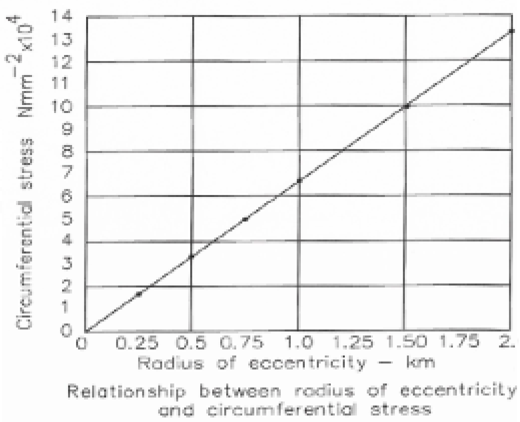


Fig A11: Relationship between the force (Newtons) needed to move a 1km x 1m x 1m element of crust and the coefficient of friction at the crust/mantle interface.

Appendix 4 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 x 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 x 10^3 kg

R = Radius of Earth (m): 6.4 x10^6 metres

ω = Angular velocity (rad s^{-1}): 7.27 x 10^{-5} rad s^{-1}

Thus Fr = Radial Outward Force (N)

= M ω^2 R

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

= 94.71 N

= c 9.65 kgf

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 crustal plates to move around Earth's surface on a frictionless mantle.

Appendix 5 Mathematical Analysis for a Rotating Rigid Body such as Rim Type Flywheels

In contradiction to the analysis given in Fig A5 & A7 and Appendix 3, this analysis simply considers the Earth as an eccentrically rotating solid body such as an unbalanced flywheel. As such it does not describe the circumferential forces which are thought to be linked to the tectonic forces resulting in plate movements but does describe the situation that would occur if the lithosphere were treated as a thin shell sphere subjected to an internal pressure with a developed 'vertical force P' (C within Fig A7 Appendix 3).

Notation		**Value**
R = Radius	=	6.4 x 1 0^6 metres
E = Eccentricity	=	1.0 x 10^3 metre
T = Thickness	=	1.0 x 10^3 metre
ρ = Density	=	2.8 x 10^3 kg m^{-3}
ω = Angular velocity	=	7.27 x1 0^{-5} rad s^{-1}
σ = Hoop Stress N m^{-2}		

Consider a cylinder of mean radius R and thickness T rotating at an angular velocity ω about its axis (Fig.A4 Appendix 3):

The mass of the portion R δθ = ρ R δθ.T

The radial force on the element = mass x acceleration = (ρ R δθ.T) Rω^2

This will produce the Hoop Stress σ.

Resolving radially

$\delta\theta$ (as $\sin\frac{1}{2}\theta \rightarrow \frac{1}{2}\theta$)

Therefore $\boldsymbol{\sigma = \rho R^2 \omega^2}$ (**Equation 4)**

If the centre of rotation is displaced δr, from the centre of mass (Fig 9 Section 3 and represented by E in Fig 18b Section 6.2.1) then the tensile force on the 'heavier side' will be increased by the following amount:

Thus, 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 values stated above:

The additional tensile stress

$= 2.5 \times 10^3 \times (7.27 \times 10^{-5})^2 \times (2 \times 10^3 \times 6.4 \times 10^6 + 10^6)$

$= 1.89 \times 10^5$ N m^{-2}

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

Thus 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, tensile stress will have a negative value

The tensile stress is thus = -1.89×10^5 N m^{-2}

This negative tensile stress is the

compression stress = 1.89×10^5 N m^{-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 in Section 7 is based on having relative movement between the outer rim or crust and the main body or mantle.

Appendix 6 NASA Science, Solar System Exploration. Updated Sept 2019

Kepler's First Law: Each planet's orbit about the Sun is an ellipse. The Sun's centre is always located at one focus of the orbital ellipse. The planet follows the ellipse in its orbit, meaning that the planet to Sun distance is constantly changing as the planet follows its orbit.

Kepler's Second Law: The imaginary line joining a planet and the Sun sweeps equal areas of space during equal time intervals as the planet orbits. This means that planets do not move with constant speed along their orbits. Rather, their speed varies so that the line joining the centres of the Sun and the planet sweeps out equal areas in equal times. The point of nearest approach of the planet to the Sun is termed the perihelion. The point of greatest separation is the aphelion, hence by Kepler's Second Law, a planet is moving fastest when it is at the perihelion and slowest at the aphelion.

Appendix 7 Statistical Calculations Relating to the Tensile Forces

Determination of the circumferential stress on the continental and oceanic crusts to a 95% confidence level

	Density Continent crust **Dc** kg/m3	Density Oceanic crust **Do** kg/m3	Equatorial radius **R** 10x exp3 km	Rotational velocity **w** 10exp-5 rad/sec	Stress on Continental crust **Fc =** 0.7854.Dc.R.w.w. /10 (N x 10exp.7) Random values	Stress on Oceanic crust **Fo =** 0.7854.Dc.R.w.w. /10 (N x 10exp.7) Random Values		Stress on Continental crust **Fc =** 0.7854.Dc.R.w.w. /10 (N x 10exp.7) Sorted in ascending order	Stress on Oceanic crust **Fo =** 0.7854.Dc.R.w.w /10 (N x 10exp.7)
1	2.715	2.8745	6.370	7.2731	71.841	76.073	1	68.689	74.763
2	2.63	2.8331	6.363	7.2889	69.830	75.216	2	68.731	74.774
3	2.779	2.8491	6.367	7.2794	73.639	75.498	3	68.785	74.811
23	2.873	2.8416	6.373	7.2803	76.217	75.382	23	69.137	74.964
24	2.74	2.8696	6.367	7.2779	72.569	76.008	24	69.138	74.970
25	2.728	2.8524	6.373	7.285	72.463	75.771	25	**69.139**	**74.970**
26	2.691	2.8532	6.373	7.2775	71.345	75.641	26	69.142	74.972
27	2.893	2.885	6.370	7.2721	76.530	76.326	27	69.146	74.976
498	2.651	2.8565	6.371	7.2869	70.430	75.899	498	72.954	75.858
499	2.84	2.8887	6.360	7.2858	75.310	76.600	499	72.959	75.861
500	2.729	2.8601	6.375	7.2849	72.524	76.001	500	**72.968**	**75.865**
501	2.828	2.8569	6.367	7.27	74.750	75.515	501	72.974	75.867
502	2.668	2.8783	6.360	7.2713	70.454	76.020	502	72.980	75.869
972	2.744	2.8815	6.371	7.2857	72.889	76.539	972	76.697	76.687
973	2.607	2.8327	6.370	7.2879	69.265	75.271	973	76.727	76.688
974	2.609	2.842	6.368	7.2845	69.245	75.420	974	76.729	76.691
975	2.886	2.8369	6.369	7.2708	76.323	75.020	975	**76.735**	**76.691**
976	2.684	2.8398	6.362	7.2833	71.133	75.274	976	76.744	76.702
977	2.811	2.8508	6.370	7.2916	74.762	75.827	977	76.757	76.707
978	2.811	2.8413	6.368	7.2843	74.604	75.408	978	76.782	76.707
979	2.893	2.8804	6.375	7.2846	76.862	76.525	979	76.798	76.713
997	2.719	2.8686	6.367	7.2798	72.054	76.020	997	76.965	76.870
998	2.806	2.8876	6.378	7.2917	74.723	76.906	998	76.993	76.885
999	2.815	2.8762	6.367	7.2728	74.463	76.074	999	77.059	76.906

Density of continental crust (Dc) - kg/m3	2.6 to 2.9
Density of oceanicl crust (Do) - kg/m3	2.83 to 2.89
Radius of Earth from pole to equator - 10exp-3 km	6.3567 to 6.3781
Rotational velocity 10exp-5 rad/sec	7.27 to 7.292

Thus the mean value of the circumferential stress (Fc) acting on the Continental crust is
Fc = 72.968 (69.139, 76.735)x 10exp.6 N to a 95% confidence limit

Thus the mean value of the circumferential stress (Fo) acting on the Oceanic crust is
Fo = 75.865 (74.970, 76.691)x10exp.6 N to a 95% confidence limit

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NOTE. The apparently old references used in the sections dealing with an overview of tectonic movements as being a function of subduction forces is justified as the original arguments have been continuously, and still are, current thinking. The bulk of this treatise deals with the mathematically related conceptual work in which tectonic movements are shown to be a derivative of the forces associated with the rotation of the Earth. There is a noticeable absence of published work on this aspect of tectonic movements.

Illustrations

As this is a not-for-profit publication, use has been made of information gleaned from various publications, mainly on the Internet. Once again, most of the illustrations seem to be repeatedly copied with minor variations by different educational and scientific organisations.

The author made several attempts (without success) to get permission for reproducing some of the illustrations dealing with the plotted motions of unbalanced shafts.

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The Author

Bob Maurer graduated as a mining metallurgist in 1956 in South Africa and worked in gold, uranium and diamond mines before studying electro-chemistry at the University of London. This took him into a number of classified research projects which included the growth of single crystals of alpha–uranium for the nuclear industry and the investigation of the hydrogen embrittlement of ultra-high tensile steels for the aerospace industry. This led to a career in the design and manufacture of instrumentation for the aerospace and petrochemical industries where he established the name Maurer Instruments as a manufacturer of highly accurate and extremely reliable NATO and petro-chemical industry-approved flowmeters. Sadly, the NRDC sponsored development of the Maurer True Mass Flowmeter for use in supersonic aircraft was inhibited by the UK Government's cancellation of the TSR2 programme. In 1985, BP Exploration commissioned Bob to design and build the complete range of crude oil sampling equipment which became the basis of the R&D programme to create the ISO3171 International Standard for the automatic sampling of crude oil for the water content. His innovative designs are now extensively copied. BP Exploration also commissioned Bob to design their multiphase flowmeter.

Bob has delivered many papers at international symposiums on flow measurement, meter proving and crude oil sampling in the UK, Europe, India and the USA and was a principal contributor to the Handbook of Fluid Flow Metering (ISBN86461 -120-7). Bob was also a member of the working committee which drew up international standards for the fiscal flow measurement of pumped crude oil.

Bob's interest in the geology of crustal movements followed on from his main hobbies of mineral and fossil collecting. It was these hobbies that took him to the Bolivian Andes and inspired him to look at the forces associated with tectonic movements and the means by which marine fossils could be transported to the heights of the Andes. He has applied an engineer's approach to the analysis of the forces responsible for such great tectonic and orogenic movements. In doing so, he has formulated the proposals within this volume in which the Earth's unbalanced rotation plays a key role and drives the relentless cycle of orogenesis and lithosphere recycling.

Bob now lives in Uxbridge, W London, UK

This work explores the nature and origin of the forces responsible for the unrelenting unidirectional movements of continental masses and in particular the break-up of Pangea from the latter part of the Permian period to the present day.

The analysis shows that the Earth, alongside the other planets, require an ‘offset centre of mass’ to allow the mutually gravitational pull between the Sun and the planets to establish a N-S axis around which the planets are caused to rotate.

The circumferential forces developed within the lithosphere due to the rotating ‘unbalanced’ or ‘wobbly’ planet are considered primarily responsible for the perpetual movement of the tectonic plates around the surface of the Earth thus allowing the continuous recycling of the lithosphere.

By implication, it is considered that the complex circulatory system of heated convection currents within the mantle have a passive rather than an active role in tectonic plate movements. This approach also allows for an alternative cycle of lithosphere regeneration to be proposed.

Cobbler’s Hole, St Anne’s Head, Dale Peninsula, Pembrokeshire, Wales. Devonian Old Red Sandstone intensely folded in the Carboniferous period during the Variscan Orogeny.

Photograph © Allan Wheeler

“To understand something,
you must be able to measure it” – Anon

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