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The Sun: Engine of the Dynamic Forces for the Movement and Deformation of the Earth's Lithosphere

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Abstract

The dynamic forces that cause the movement and deformation of the Earth's crust have been the subject of debate for decades. Recent studies, based mainly on the analysis of stresses, have suggested that tectonic plate dynamics is mainly controlled by gravitational potential energy, subduction, the expansion of oceanic transform faults, thermal convection, plumes, etc. This shows that for over sixty years, geophysicists have considered plate tectonics as a unique and direct consequence of the Earth's internal activity. However, the Earth is not alone in the universe; it is part of the Milky Way and in particular the Solar System where the Sun is the dominant gravitational mass. In this article, I take a gravitomagnetic approach of the action of speed on the moving bodies and examine the action (forces) of the Sun's gravitational field on the rotating masses of the Earth verify that there are dynamic forces generated by solar gravity acting on lithospheric plates through a comparison of my model of tectonic plate velocities with GPS data (not to be confused with the action of the lunar tide on earth). The results indicate that my model is consistent with data for the Eurasia (EU), Pacific (PA), North American (NA), South American (SA) and Australia (AU) plates in the ITRF 2000 and ITRF 2005 Terrestrial Reference system. This suggests that the various layers of the Earth, including its crust, the lithosphere, the asthenosphere, the upper and lower mantle and the core, undergo additional stress to that resulting from the internal activity of the Earth. My results provide new perspectives on heat flow, lithospheric rheology and a better understanding of earthquakes and dynamic of plate tectonics.

Keywords

Dynamics of Lithospheric Plates, Action of the Sun on the Earth, Speed of

Tectonic Plates, Gravitomagnetism, Deformation of the Earth's Crust, Rheology of the Lithosphere

1. Introduction

The theory of plate tectonics is widely accepted. It states that mechanical energy is dissipated in orogenic zones where there are horizontal movements between rigid lithospheric plates. The theory's success comes from the fact that within-plate deformations are much less significant than movements along seismic deformation zones. Thus, the movement of plates on the surface of the globe suggests that they are more or less rigid. The United States deep sea drilling program Joides (Joint Oceanographic Institutions for Deep Earth Sampling) has tested the seafloor spreading hypothesis of H.H. Hess concerning the distribution of magnetic anomalies [1]. It has confirmed that the differential movements of lithospheric plates are of the order of a few centimeters per year—or several thousand kilometers per hundred million years. If I consider that intra-plate movements are negligible then it can be assumed as a first approximation that these spherical caps are perfectly rigid and that their borders are marked by seismic activity. The boundaries of these plates can therefore be simply defined and used to describe the specific kinematics of the spheroid that is the Earth (see **Figure 1**).

For over sixty years, geophysicists have attempted to perfect the theory of continental drift. Arthur Holmes, amongst others, suggested that thermal convection in the Earth's mantle produced the necessary force to produce continental movements [2] [3]. However, there is still no comprehensive physical theory that predicts how plate tectonics work.

This paper argues that the additional forces required for the movement of lithospheric plates and the accompanying stresses could be produced by external events to Earth. I argue that the influence of the solar gravitational field on the rotating mass of the Earth supports a theory that can accurately predict the movement of the lithosphere relative to the asthenosphere, which is considered as a reference (especially in relation to hotspots). We show that this strength of the movement is at least one hundred times greater than the tidal forces of the Sun and the Moon together, and that these tidal forces have a negligible role in the movement of tectonic plates [4]. My argument is based on earlier work [5]-[10] and takes as a starting point results related to the framework of gravitomagnetism implied by Einstein's general relativity theory (GR), with γ representing the acceleration produced by the earth according to the modified Newton relation see publications [5]-[10].

We have the following relation:

$$\gamma = \frac{G \cdot M}{r^2} \cdot \frac{1}{\sqrt{1 - v/c}} \tag{1}$$

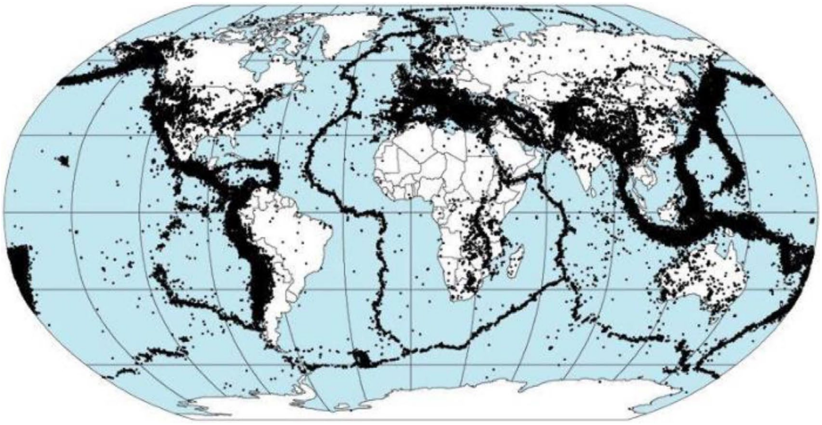

Figure 1. World Seismicity Map 1964-2008. (Source: International Seismological Center)

2. Complete Symmetry for the Sun and the Planets

In the relation 1, v is the projection of the vector speed along the radial radius r (distance between the sun and the earth), and G is the gravitational constant. An interesting characteristic of relation 1, is that acceleration is no longer independent of the sign of the velocity v of the test particles making up the mass M, the source of the gravitational field.

I now examine the case of gravitational masses, in particular the Solar System and the Sun whose volumetric expansion and mass are far greater than that of the planets. It is common knowledge that the planets revolve around a stationary Sun which itself rotates upon its axis. Over a short time, span, the planets can also be considered as stationary in relation to the Sun and mass ΔM_{sun} of the two hemispheres of the Sun moving with speed $+v$ or $-v$ in relation to the planets (**Figure 2**). Speed v is defined as the relative speed between the Sun's hemispheres and the planet in question, in this case the Earth. This does not take into account the influence of the other planets in the Solar System. The relative speed of the Sun's rotation seen by a test body ΔM_x belonging to the Earth is almost zero because it is subject to speeds $+v$ and $-v$ of both hemispheres of the Sun (see **Figure 2**). Extended to the total mass of the Earth this speed is considered to have no effect on the action of the gravitational field of the Sun. By applying (1) and replacing v by zero, acceleration $\gamma = \frac{G \cdot M}{r^2}$ is equal to Newton's classic relation.

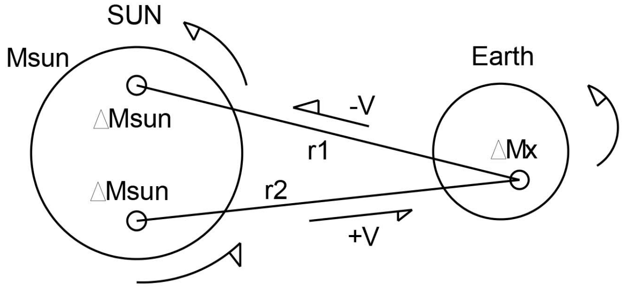

Figure 2. Cancellation of the Sun's rotation speed for mass ΔM_x.

However, this is not entirely true, **Figure 2** shows that the distances r_1 and r_2 (and the density of the sun's matter) are not equal. However, this difference does not present a serious error in the calculations, for the purposes of my application I will not take this into account (the maximum is about 10^{-1} m/s vs 466 m/s for the Earth). Applying the same reasoning used for the Sun to the Earth, **Figure 3** shows the speeds of the Earth's hemispheres to be $+v$ and $-v$ (the speed of the Earth's rotation around its axis) and this relative speed is taken into account in (1) in the acceleration γ produced by the Sun on the element of mass ΔM_x on the Earth.

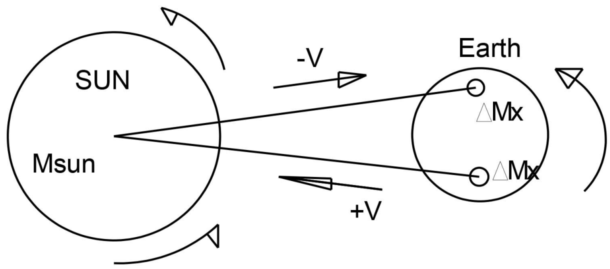

Figure 3. Relative speed of the Earth's rotation for mass ΔM_x.

3. Reaction between the Sun's Gravitational Field and the Earth's Rotation

Using the polar coordinates and considering the Earth as having a quasi-continuous density from the inner core to the upper mantle I consider mass ΔM_x who's the infinitesimal volume $\mathrm{d}V$ can be defined as:

$$\mathrm{d}V = r^2 \cdot \sin\phi \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta \tag{2}$$

The infinitesimal mass $\mathrm{d}m$ can be defined as:

$$\mathrm{d}m = \mu \cdot r^2 \cdot \sin\phi \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta \tag{3}$$

Here μ is the density of the zone on the Earth and r is the vector radius of the test mass ΔM_x (see **Figure 4**).

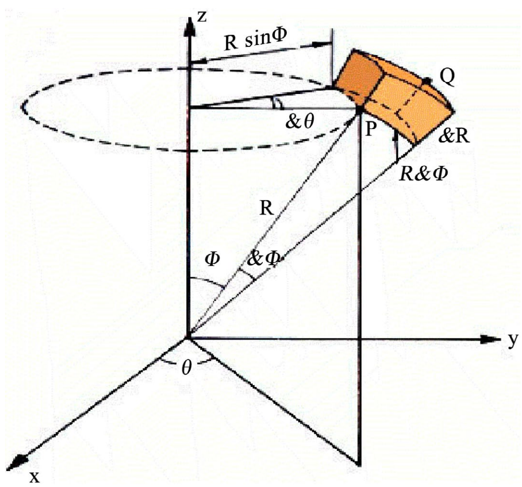

Figure 4. Polar coordinates of the point Q of mass ΔM_x on the Earth.

To facilitate the calculations that follow, I consider the distance between the center of the Sun and any mass ΔM_x, as equal to the Earth-Sun distance. This distance will vary based solely on the position of the Earth around the Sun and the eccentricity of its orbit is $r_{earthsun} = R_0 \cdot (1 - e_x \cdot \cos\lambda)$, where λ represents the position of the Earth with respect to the Sun and has the value of 0 to 2π, while R_0 is the Earth-Sun distance equal to 1.496×10^{11} m where $\lambda = 0$ in winter.

Figure 5 shows the spherical coordinates of the Earth with the unit vectors e_1, e_2 and e_3. The unit vector e_4 represents the direction of the center of the Sun at an angle e_4, O, e_1 equal to λ_{so} which represents the angle of inclination of the axis of rotation of the Earth on the Earth-Sun radius vector, which varies with the position of the Earth in its orbit around the Sun, and λ_s is the tilt of the rotation axis of the Earth with respect to the ecliptic plane, it is equal to 23.4˚.

The curvilinear unit vectors e_r, e_ϕ and e_θ are written according to e_1, e_2 and e_3 (**Figure 5**) as follows:

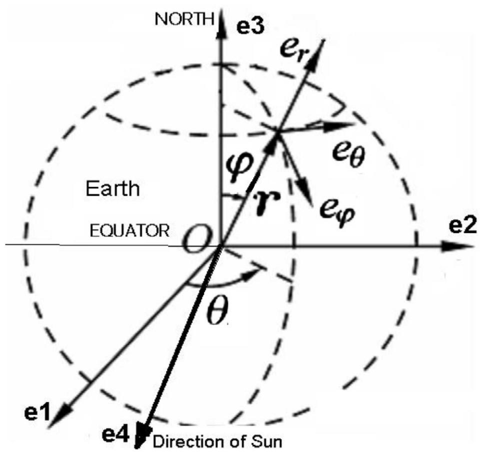

Figure 5. Spherical coordinates of the Earth.

$$
\begin{aligned}
&e_r = e_1 \cdot \sin\phi \cdot \cos\theta + e_2 \cdot \sin\phi \cdot \sin\theta + e_3 \cdot \cos\phi \\
&e_\phi = e_1 \cdot \cos\phi \cdot \cos\theta + e_2 \cdot \cos\phi \cdot \sin\theta - e_3 \cdot \sin\phi \\
&e_\theta = -e_1 \cdot \sin\theta + e_2 \cdot \cos\theta \\
&e_4 = e_1 \cdot \cos\lambda_{so} - e_3 \cdot \sin\lambda_{so} \\
&\text{With } \lambda_{so} = \arcsin(\sin\lambda_s \cdot \cos\lambda)
\end{aligned}
\tag{4}
$$

The calculation of the reaction energy between the gravitational field of the Sun and the Earth's elemental rotating masses ΔM_x with coordinate function r, ϕ, θ and λ will be along the radius vector e_4. For this reason, I need to calculate the projections along e_4 of the speed $v_{planet} = r \cdot \sin\phi \cdot \omega_{earth}$ (speed of the Earth around its axis) and the infinitesimal path $\mathrm{d}h_{planet} = r \cdot \sin\phi \cdot \mathrm{d}\theta$ (working of the gravitational force).

I also need to define the projection of v_{planet} and $\mathrm{d}h_{planet}$ along e_4 (or here: v_{e4} and $\mathrm{d}h_{e4}$) created by the inclination of the Earth's axis of rotation with the ecliptic that varies with λ (the position of the Earth in its solar orbit). This calculation is relatively simple, because we can project v_{planet} and $\mathrm{d}h_{planet}$ defined in the spherical coordinate system based on unit vectors e_1, e_2 and e_3, onto the vector e_4 axis connecting the Sun to the Earth. Finally, the unit vector e_4 is given by the following relationships:

$$v_{e4} = \frac{r}{1 + 62.3 \cdot \sin(\Omega_{cb})} \cdot \sin\phi \cdot \omega_{cb} \cdot \left[-\sin\theta \cdot \cos\left(\arcsin\left(\sin\lambda_s \cdot \cos\lambda\right)\right)\right] \quad (5)$$

$$\mathrm{d}h_{e4} = \frac{r \cdot \sin\phi}{1 + 62.3 \cdot \sin(\Omega_{cb})} \cdot \left[-\sin\theta \cdot \cos\left(\arcsin\left(\sin\lambda_s \cdot \cos\lambda\right)\right)\right] \cdot \mathrm{d}\theta \quad (6)$$

Here Ω_{cb} (**Figure 6**) (cb for celestial bodies, Ω_{cb} is equal to λ_s (23.4˚) for the Earth (for more information see [5] [9].

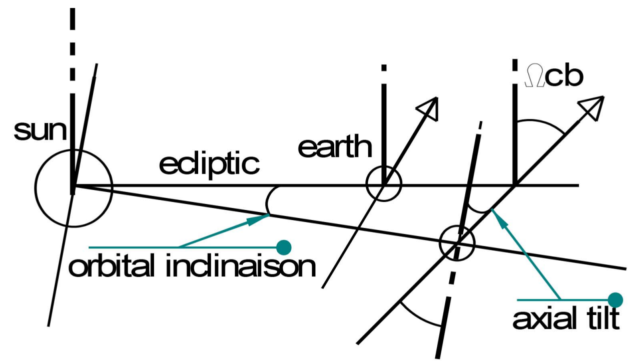

Figure 6. Definition of the angle Ω_{cb}.

I can now write the relation of the reaction energy $\mathrm{d}W$ between the mass of the Sun (M_{sun}), and the infinitesimal rotating masses $\mathrm{d}m$ moving with speed v_{e4} along the Earth-Sun axis on the infinitesimal distance $\mathrm{d}h_{e4}$, defined by (3), (5) and (6) as:

$$\mathrm{d}W = G \cdot M_{sun} \cdot \frac{1}{\sqrt{1 - \frac{v_{e4}}{c}}} \cdot \frac{\mathrm{d}h_{e4}}{R_{earthsun}^2} \cdot \mathrm{d}m \quad (7)$$

Equation (7) is the classic relationship describing the action of the gravitational strength of the sun on the $\mathrm{d}m$ elementary masses of the Techtronic plate of the earth. I note that when rotation speed is null, this energy becomes equivalent to Newton's classical work on forces, *i.e.*, rotation of the mass $\mathrm{d}m$ around the terrestrial axis. In this case, the total force will be very low and only a solar tide effect will be felt on Earth. I can easily verify that this energy (solar tide effect) is much lower than the energy induced by the speed v_{e4}, and for this reason I do not take it into account in this study. Next, I integrate and develop (7) between the limits: R_1 and R_2 for the variation of r (see **Figure 7**), $\phi(latitude)$ and $\phi(latitude) + \Delta\varphi$ for the variation of the latitude and, 0 at 2π for θ where:

$$\int_0^{2\pi} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi} \int_{R_1}^{R_2} G \cdot M_{sun} \cdot \frac{1}{\sqrt{1 - \frac{v_{e4}}{c}}} \cdot \frac{\mathrm{d}h_{e4}}{R_{earthsun}^2} \cdot \mathrm{d}m$$

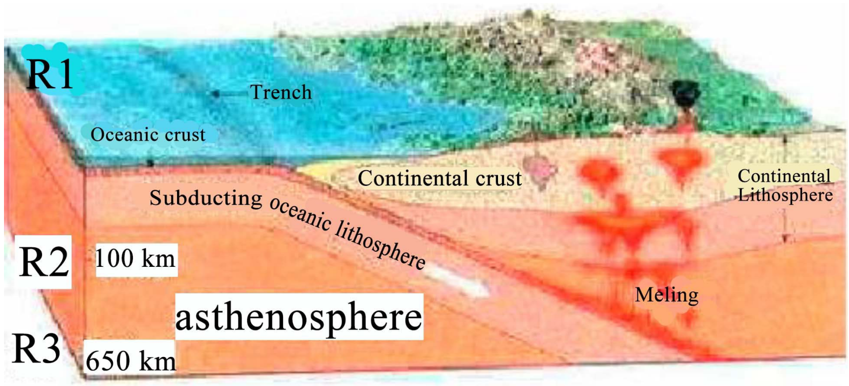

Figure 7. Structure of oceanic and continental lithosphere plates.

As the v_{e4}/c ratio is very small compared with unity. I can replace $1\Big/\sqrt{1-\frac{v_{e4}}{c}}$ by $1+\frac{1}{2}\frac{v_{e4}}{c}$. Then I can write:

$$W_{\overrightarrow{e4}} = \int_0^{2\pi}\int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi}\int_{R_1}^{R_2} G\cdot M_{sun}\cdot\frac{1}{R_{earthsun}^2}\cdot\left[\int\left(1+\frac{1}{2}\frac{v_{e4}}{c}\right)\cdot \mathrm{d}h_{e4}\right]\cdot \mathrm{d}m \quad (8)$$

The indefinite integral of (8) is derived from the fact that the speed v_{e4} and $\mathrm{d}h_{e4}$ are functions of both the angle of rotation θ and $\mathrm{d}\theta$. Solving (8) allows us to write the following relation for the total reaction energy $W_{\overrightarrow{e4}}$ along vector $\overrightarrow{e_4}$ (on the Sun-Earth axis):

$$W_{\overrightarrow{e4}} = \frac{\Delta\theta}{2\pi}\int_0^{2\pi}\int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi}\int_{R_1}^{R_2} G\cdot M_{sun}\cdot F(r,..)\frac{\frac{r\cdot\sin\phi}{1+62.3\cdot\sin\Omega_{cb}}}{\left[R_o\cdot\left(1-e_x\cdot\cos\lambda\right)\right]^2}\frac{r^2\sin\phi\cdot\mu(r)}{1+62.3\cdot\sin\Omega_{cb}}\cdot \mathrm{d}r\cdot \mathrm{d}\phi\cdot \mathrm{d}\theta \quad (9)$$

With $F(r,..)$ which represents the value obtained by the resolution of the indefinite integral located in the relationship (8) above equal to

$$F(r,..) = \cos\left(\arcsin\left(\sin\lambda_s\cdot\cos\lambda\right)\right)\cos\theta + \frac{\frac{r}{1+62.3\cdot\sin\Omega_{cb}}\cdot\sin\phi\cdot\omega_{cb}}{2c}\cos\left(\arcsin\left(\sin\lambda_s\cdot\cos\lambda\right)\right)^2\cdot\left(\frac{\theta}{2}-\frac{\sin 2\theta}{4}\right)+Ct$$

In this relation, λ_s represents the inclination of the axis of the Earth's rotation with respect to the ecliptic (for the Earth this is equal to 23.4˚), ω_{cb} represents the Earth's rotational speed in rad/s, Ω_{cb} is defined above and in the case of the Earth is equal to λ_s (23.4˚). The term $\Delta\theta$ represents the angular dimension of the Earth's mass considered in (9), which is also part of ($\frac{\Delta\theta}{2\pi}$) of the Earth's rotating ring of total value 2π (following the integration of 0 at 2π on θ), λ is the angle traveled by the Earth around the Sun, ranging from 0 at perigee to π at apogee and Ct is one pseudo-constant of integration introduced in the calculation of the indefinite integral (see (8)) function of θ.

It is interesting to note that $F(r,..)$ has two components; the first is the action defined purely by the Newtonian gravitational field independent of the rotation of the Earth; and the second is a function of the Earth's speed of rotation. The calculation of Ct is relatively simple; indeed, its derivative according to the angle θ is null, and it only depends on the latitude represented by $\left(\frac{\pi}{2}-\phi\right)$, r and λ. Since r is the thickness of the asthenosphere (considered here to be the limit of heat conductivity of the upper mantle as a working hypothesis) and λ depends on the Earth's rotation around the Sun, the latitude $\left(\frac{\pi}{2}-\phi\right)$ is the only variable in the calculation.

In order to calculate Ct, I need to define a function $Ct(\phi)$ (ϕ is defined in Figure 4). This function is relatively easy to find and takes the following empirical form:

$$Ct(\phi)=a\cdot\sin\left(\frac{\left(\frac{\pi}{2}-\phi\right)^2}{\left|\frac{\pi}{2}-\phi\right|}\cdot b\right)+c \quad (10)$$

$\left(\frac{\pi}{2}-\phi\right)$ represents the latitude of the point in question, and the coefficients *a*, *b* and *c* are determined by the same heat flow calculations found in [10]. In my application, coefficients have the following values: $a=-8.3\times10^{-8}$ $b=2.27$ $c=1\times10^{-7}$.

$Ct(\phi)$ can then be determined empirically, leaving the coefficients defined above to vary on a case-by-case basis. It is clear that it can be reformulated as:

$$Ct(\phi)=-8.3\times10^{-8}\cdot\sin\left(\frac{\left(\frac{\pi}{2}-\phi\right)^2}{\left|\frac{\pi}{2}-\phi\right|}\cdot 2.27\right)+1\times10^{-7} \quad (11)$$

At this stage of my calculations, I can define the projection of the forces on the curvilinear unit vectors e_r, e_ϕ and e_θ, in order to write W_r, W_θ and W_ϕ. I note that the direction of these energies (of the work of the forces) is westward for e_θ, northward for e_ϕ and from the center of the Earth to e_r. In equation 9, $F(r,..)$ becomes:

$$F_\phi=\left[\sin\phi\cdot\sin\lambda_s\cdot\cos\lambda+\cos\theta\cdot\cos\phi\cdot\cos\left(\arcsin\left(\sin\lambda_s\cdot\cos\lambda\right)\right)\right]\cdot F(r,..)$$

$$F_\theta=-\sin\theta\cdot\cos\left(\arcsin\left(\sin\lambda_s\cdot\cos\lambda\right)\right)\cdot F(r,..)$$

$$F_r=\left[\cos\theta\cdot\sin\phi\cdot\cos\left(\arcsin\left(\sin\lambda_s\cdot\cos\lambda\right)\right)-\cos\phi\cdot\sin\lambda_s\cdot\cos\lambda\right]\cdot F(r,..)$$

Finally, substituting the value of $F(r,..)$ in (9) I obtain:

$$W_\theta=\int_0^{2\pi}\int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi}\int_{R_1}^{R_2}\frac{\Delta\theta}{2\pi}\cdot G\cdot M_{sun}\cdot F_\theta(r,..)\frac{\frac{r\cdot\sin\phi}{1+62.3\cdot\sin\Omega_{cb}}}{\left[R_o\cdot\left(1-e_x\cdot\cos\lambda\right)\right]^2}\frac{r^2\sin\phi\cdot\mu(r)}{1+62.3\cdot\sin\Omega_{cb}}\cdot\mathrm{d}r\cdot\mathrm{d}\phi\cdot\mathrm{d}\theta$$

$$W_\phi = \int_0^{2\pi}\int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi}\int_{R_1}^{R_2} \frac{\Delta\theta}{2\pi}\cdot G\cdot M_{sun}\cdot F_\phi(r,..)\frac{\frac{r\cdot\sin\phi}{1+62.3\cdot\sin\Omega_{cb}}}{\left[R_o\cdot(1-e_x\cdot\cos\lambda)\right]^2}\frac{r^2\sin\phi\cdot\mu(r)}{1+62.3\cdot\sin\Omega_{cb}}\cdot dr\cdot d\phi\cdot d\theta$$

$$W_r = \int_0^{2\pi}\int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi}\int_{R_1}^{R_2} \frac{\Delta\theta}{2\pi}\cdot G\cdot M_{sun}\cdot F_r(r,..)\frac{\frac{r\cdot\sin\phi}{1+62.3\cdot\sin\Omega_{cb}}}{\left[R_o\cdot(1-e_x\cdot\cos\lambda)\right]^2}\frac{r^2\sin\phi\cdot\mu(r)}{1+62.3\cdot\sin\Omega_{cb}}\cdot dr\cdot d\phi\cdot d\theta \quad (12)$$

The term $\mu(r)$ represents the density of the elementary mass dm that is a function of its coordinates. Although the density varies from one point to another depending on r,θ and ϕ, in order to simplify the calculation, I consider the Earth as concentric from the point of view of density and write $\mu(r)$ in the form of a polynomial as follows:

$$\mu(r) = \left[-4.9553\times10^{-16}\cdot\left(\frac{r}{m}\right)^3 + 7.3899\times10^{-9}\cdot\left(\frac{r}{m}\right)^2 - 0.0372\cdot\left(\frac{r}{m}\right) + 67525.59\right]\frac{kg}{m^3} \quad (13)$$

If the average density of the point in question is accurately known, it is sufficient to substitute $\mu(r)$ by its new value. As r varies from 4.5 × 10^6 m to r_{earth} I obtain the following graph; Figure 8, where $\mu data_i$ is density data derived from the propagation velocities of acoustic waves in the Earth, $\mu(r)$ idem μ_i and r the radius where:

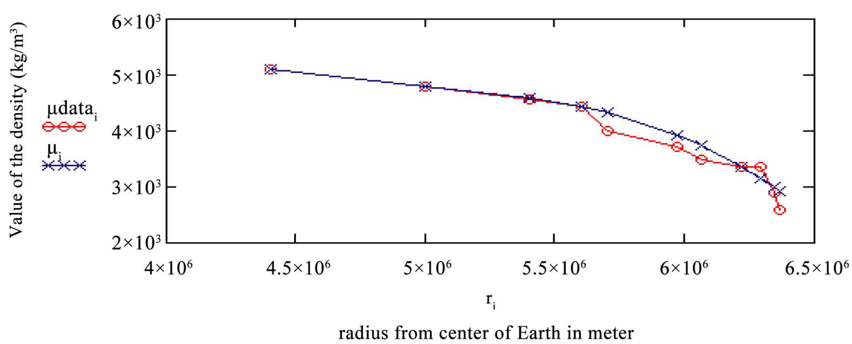

Figure 8. Density of the Earth's layer.

The Earth has two types of lithospheres: the oceanic lithosphere is about 10km thick and is composed of basalt with a density of about 3.3 × 10^3 kg/m^3, while the continental lithosphere is much more heterogeneous, it can be lower in density and is 30 - 100 km thick. For the most realistic results, I will consider it in the following.

4. Applications and Discussion of the Theoretical Results to Reduced Heat Flow

Relationship between *W* and Reduced Heat Flux

I assume that the mantle and crust heat flux is proportional to the average surface heat flux. [11] argued that mantle heat flux represents 40% of the regional average surface heat flux. Despite the fact that their measures were based on a small dataset, I consider here that they are valid up to a minimum scale of about 300 km [12]. Average heat flux data suggest an empirical relationship of the form $Q = Q_o + b \cdot \bar{H}$.

For the purposes of this study, I redefine the relationship as follows:

$$\bar{Q} = \overline{Q_o} + b \cdot \bar{H} + q_o \tag{14}$$

where $\bar{Q}$ represents average heat flux across the designated area and $\bar{H}$ is heat production, $\overline{Q_o}$ is average reduced heat flux, b represents the thickness of a shallow layer enriched by radiogenic elements, while q_o depends on latitude and its value of around 12 mW/m² is in direct relation with $Ct(\phi)$, which is defined above. Equation (14) reflects changes in average heat flux on a larger scale (>200 km) and is based on a very large dataset. It implies that reduced heat flux $\overline{Q_o}$ is the same at a certain depth and latitude of the crust in all areas. The assumed value $\overline{Q_o}$ is clearly shown in (9), which expresses the gravitational action of the Sun on the moving masses of the Earth. This data can be checked against the Q_o data provided in **Table 1** (below), from the study by [13].

Table 1. Reduced heat flux for the linear data fit of individual areas.

N°	Terrain	Reduced Heat Flow mW/m² (Q_o data)	Latitude	References
1	Baltic Shield	24	66 N	Balling, 1995 [14]
2	Brazil Coastal	43.152	25 S	Vitorello *et al.*, 1980 [15]
3	Central Australia	48.8	23 S	McLaren *et al.*, 2001 [16]
4	Eastern USA Phanerozoic	26.961	40 N	Roy *et al.*, 1968 [17]
5	Eastern USA Proterozoic	26.524	41 N	Roy *et al.*, 1968 [17]
6	Fennoscandia	23.5	54 N	Kukkonen *et al.*, 2001 [18]
7	Maritime	34.54	30 N	Hydman *et al.*, 1979 [19]
8	Piedmont	28.61	37 N	Costain *et al.*, 1986 [20]
9	Ukraine	24.32	49 N	kutas, 1984 [21]
10	Wyoming	26.25	42 N	Decker *et al.*, 1988 [22]
11	Yilgarn	33.334	32 S	Jaeger, 1970 [23]

To compare equation (9) (heat production Q_o due to the gravitational action of the Sun on the Earth, W) with Q_o data (reduced heat flux, **Table 1**), I must extend (9) in order to calculate heat flux up to depths of the order of 660 km for the whole of lithosphere and asthenosphere, and the upper mantel. The calculation of heat flow and heat production is based on a 1m² column that is approximately 660 km deep. In this area, most heat transfer occurs through thermal conduction, and I can assume that the heat produced as a result of the gravitational effect of the Sun is equal across wide areas and therefore comparable to the reduced heat flow Q_o shown in (14). Heat propagation is weakest in the lower mantle; it is no longer completely the result of thermal conduction but varies according to the geography of the area and is comparable to heat production $\bar{H}$ shown in (14).

Reduced heat flow (Q_o) in the 660 km-deep lithosphere asthenosphere and the upper mantel is calculated by applying (9) (W). However, this relation represents only one 24-hour rotation of the Earth and relies on a defined value for the position of the Earth (λ) around the Sun. It is not, therefore, a weighted average over an entire year. To find the weighted yearly average, I must integrate (9) at angle λ from 0 to 2π as follows:

$$W_t = Q_o = \frac{1}{T_{earthsun}} \cdot \frac{365}{2\pi} \cdot \int_0^{2\pi} W \cdot \mathrm{d}\lambda \tag{15}$$

In (15), W_t represents the heat energy produced all the year in the elementary volume measured in watts per square meter. $T_{earthsun}$ represents the time for one revolution of the Earth around the Sun.

There are several rheological models of the continental lithosphere [24] [25]. In broad terms, I consider the lithosphere (including the crust) as a rigid material about 100 km deep that responds to tectonic forces. It sits on top of the ductile upper mantle and of the transition zone that are approximately 560 km deep, where heat is exchanged with the solar gravitational reaction. Consequently, the limits of the integration of (9) for the calculation of reduced heat flow Q_o are as follows: $R_1 = R_{earth} - 660\ \text{km}$ and $R_2 = R_{earth} - 100\ \text{km}$ and the limits of integration of (12) for the calculation of tectonic forces and the strain rate are: $R_2 = R_{earth}$ and $R_1 = R_{earth} - 100\ \text{km}$.

The following calculates the heat flow for $\Delta\phi$ and $\Delta\theta$ (of a length of 1 m):

$$\Delta\theta = \frac{1\ \text{m}}{r_{earth} \cdot \sin\left(\phi(latitude)\right)},\ \Delta\varphi = 0.00000899 \cdot \frac{\pi}{180} \quad \text{or} \quad \phi(latitude) = \pi \cdot \frac{90 - latitude}{180}$$

The application of (15) leads to the following reduced heat flow (Q_o = Calculus and Q_o data = data) Graph.

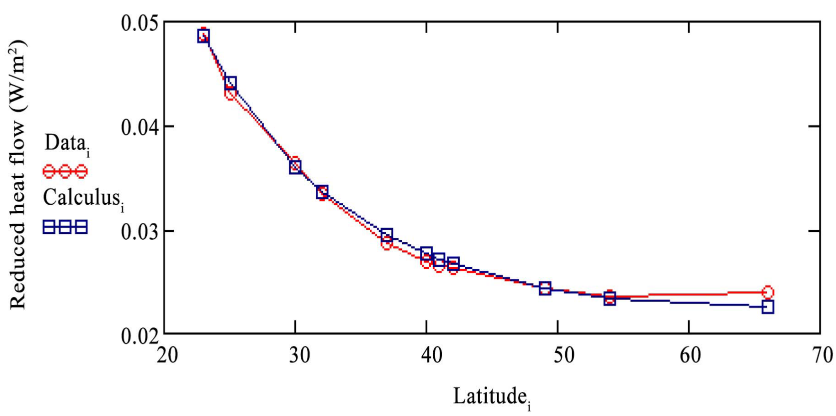

Figure 9. Application of W_t in regards of the data Q_i.

It is interesting to note that **Figure 9** shows that reduced heat flow Q_o = Calculus decreases at higher latitudes. This is not unusual, and several other authors have noted the phenomenon. For example, **Figure 10** shows the results from a study of the north-northwest of Western Australia (Perth Basin) carried out by the company [26]. For further discussion of the reduced heat flow problem see [10].

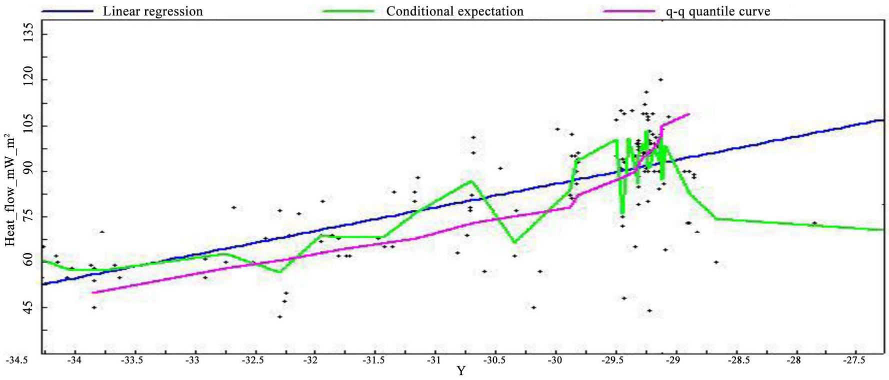

Figure 10. Heat flows in mW per m^2 for y axis and latitude for x axis.

5. Applications and Discussion of the Theoretical Results to the Movements of Tectonic Plates

5.1. Viscous behavior of the Earth's Mantle

The action of Sun on the production of heat in the Earth is directly related to the movement of the continental and oceanic plates. I use the heat flow relationships defined above in my new concept of the movement of the tectonics plates. Here I only discuss the action of the Sun on the moving masses of the Earth and neglect the relatively small contribution of the planets and the Moon. To apply (12) to plate tectonics, I must find the relation between the strain rate and tensile energy of the rigid lithosphere. The laws of viscosity allow us to write the following equation:

given the constraint (Pa) ≈ viscosity (Pa·s) × strain rate (s^{-1})

for example, when the pressure from the plate subduction process gives rise to a viscosity. The viscous resistance of the mantle due to plate movements is given by:

$$\sigma \approx \eta \cdot \frac{\mathrm{d}\varepsilon_v}{\mathrm{d}t} \quad (16)$$

In this equation, σ represents the constraint in Pa, η is viscosity measured in Pa·s and $\frac{\mathrm{d}\varepsilon_v}{\mathrm{d}t}$ is the viscous strain rate measured in s^{-1}. The constraint σ is similar to the pressure P of plate subduction over the mantle and I can therefore assimilate P as σ. For example, viscosity η will be in the order of $\eta = \frac{\alpha \cdot \rho \cdot \Delta T \cdot g \cdot e \cdot d}{v} \approx 10^{22}\ \mathrm{Pa \cdot s}$, given a subducting plate with thickness $e = 100$

km, upper mantle thickness $d = 700$ km, speed v equal to 5cm/year, $\Delta T \approx 20\ \mathrm{K}$, α (coefficient of thermic expansion) equal to $5 \times 10^{-5}\ \mathrm{K}^{-1}$, $\rho = 3000\ \mathrm{kg/m^3}$ and $g = 10\ \mathrm{m \cdot s^{-2}}$.

More accurate calculations lead to depth-dependent values for the viscosity of the upper mantle, in particular the lithosphere (excluding the crust) of 2×10^{20} to 10^{22} Pa·s [27]. Here, I take an average value of 1×10^{22} Pa·s. However, simplification is required, in order to move a plate, the pressure must be at least equal to the resistance due to the viscosity η of the upper mantle. To complete (16), which defines the Newtonian viscous behavior, I must also take into account elastic solid behavior together with ε_e the elastic deformation, *i.e.*, the following pair of equations:

$$\begin{gathered} \sigma \approx \eta \cdot \frac{\mathrm{d}\varepsilon_v}{\mathrm{d}t} \\ \sigma \approx E \cdot \varepsilon_e \\ \varepsilon_t = \varepsilon_v + \varepsilon_e \end{gathered} \tag{17}$$

From (17) I can easily deduce the following relationship:

$$\frac{\mathrm{d}\varepsilon_t}{\mathrm{d}t} = \frac{1}{E} \cdot \left[\frac{\sigma}{\tau_m} + \frac{\mathrm{d}\sigma}{\mathrm{d}t} - \frac{\mathrm{d}E}{\mathrm{d}t} \cdot \frac{\sigma}{E} \right] \tag{18}$$

The ratio $\frac{\mathrm{d}\varepsilon_t}{\mathrm{d}t}$ represents the total strain rate, E is the elastic modulus in Pa (similar to Young's modulus) and τ_m is Maxwell's relaxation time, equal to $\frac{\eta}{E}$. The elastic modulus E and the viscous resistance σ are equivalent to pressure forces. In order to apply this to plate movements, I must find a correspondence between these two entities and the dissipated energy responsible for lithospheric movements. One close constant is:

$$\sigma \propto W_\sigma \text{ and } E \propto W_\eta \tag{19}$$

In this equation, W_σ represents the energy necessary to maintain constant motion of the plate, this is a kinetic energy. W_η represents the energy required to overcome the viscous forces between the lithosphere and the asthenosphere in the upper mantle of the earth. The pressures P_σ and P_η in the energy function can be written as follows:

$$P_\sigma = W_\sigma \cdot \frac{1}{d \cdot S} \approx \sigma \quad \text{and} \quad P_\eta(E) = W_\eta \cdot \frac{1}{d \cdot S} \approx E .$$

Without changing the meaning of (18), for a known displacement d and surface S, σ can be replaced by W_σ, and E can be replaced by W_η, which becomes:

$$\frac{\mathrm{d}\varepsilon_t}{\mathrm{d}t} = \frac{1}{W_\eta} \cdot \left[\frac{W_\sigma}{\tau_m} + \frac{\mathrm{d}W_\sigma}{\mathrm{d}t} - \frac{\mathrm{d}W_\eta}{\mathrm{d}t} \cdot \frac{W_\sigma}{W_\eta} \right] \tag{20}$$

The solution of (20) is relatively easy to find using ε_t as the coefficient of deformation:

$$W_\sigma = W_\eta \cdot \varepsilon_t \cdot \frac{1}{2 + \frac{T}{\tau_m}} \tag{21}$$

This relation gives the kinetic energy W_σ needed to maintain the movement of the plate as a function of the total energy W_η applied to it. Most of the energy W_η cancels the forces resulting from the viscosity of the asthenosphere.

The relaxation time of the plate-mantle system is of the order of a million years, and it is important in the calculation of plate speed, where τ_m is much smaller than T, T predominates. T represents the orogenic (or tectonic) cycle, and it is the current age of the Earth $t_{earth} = 4.5 \times 10^9$ years (generally written as 450×10^6 years or $\frac{t_{earth}}{10}$). T takes the value $t_{earth} + t$ where t varies (here t is the variable time) from 0 to T_{earth} (24h). Finally, I obtain the simple relationship W_σ:

$$W_\sigma = W_\eta \cdot \varepsilon_t \cdot \frac{1}{2 + \frac{t_{earth} + t}{\tau_m}} \tag{22}$$

Obviously, t is much smaller than t_{earth} is almost neglible in (22); however, it is important at the time of the early formation of the Earth and the transformation of Pangea.

5.2. Calculation of the Strain Coefficient and Strain Rate of the Lithosphere

As stated above, W_σ is the kinetic energy of the plate ($W_\sigma \approx \frac{1}{2}\Delta M \cdot v^2$), which allows us to formulate the lateral and vertical velocities in the three directions e_r, e_θ and e_ϕ. I can replace W_η in (22) by W_r, W_θ and W_ϕ in (12). Similarly, for speed v_θ towards the west (or east), v_ϕ to the north (or south), and speed v_r toward (or away from) the center of the Earth, I can write equivalent equations with the same form as (12). The kinetic energy is given by:

$$v_\phi = \sqrt{\frac{\frac{2}{2 + \frac{t_{earth} + t}{\tau_m}} \cdot \varepsilon_{\phi t} \cdot \frac{1}{2\pi} \cdot \int_0^{2\pi} W\phi \cdot \mathrm{d}\lambda}{\int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r^2 \cdot \sin\phi \cdot \mu(r) \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta}} \tag{23}$$

$$v_\theta = \sqrt{\frac{\frac{2}{2 + \frac{t_{earth} + t}{\tau_{m\theta}}} \cdot \varepsilon_{\theta t} \cdot \frac{1}{2\pi} \cdot \int_0^{2\pi} W_\theta \cdot \mathrm{d}\lambda}{\int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r^2 \cdot \sin\phi \cdot \mu(r) \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta}} \tag{24}$$

$$v_r = \sqrt{\frac{\frac{2}{2 + \frac{t_{earth} + t}{\tau_{mr}}} \cdot \varepsilon_{rt} \cdot \frac{1}{2\pi} \cdot \int_0^{2\pi} W_r \cdot \mathrm{d}\lambda}{\int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r^2 \cdot \sin\phi \cdot \mu(r) \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta}} \tag{25}$$

(modification for the relationship (23), read $\tau_{m\varphi}$ instead of τ_m)

In these equations $\varepsilon_{\phi t}, \varepsilon_{\theta t}, \varepsilon_{rt}$ represent the strain coefficients for the three directions e_r, e_θ and e_ϕ (see **Figure 5**) and $\tau_{m\theta}, \tau_{m\phi}, \tau_{mr}$ represent the relaxation time for the same orientations. The denominators in equations 23, 24 and 25 represent the portion of mass ΔM of the plate in question. In order to simplify these equations, the energies W_σ and W_η are applied between the lithosphere, which has viscosity η and is 100 km thick (including the rigid crust) and the ductile asthenosphere in the upper mantle that is 550 km thick (**Figure 7**).

As Global Positioning System (GPS) measurements of plate speed are relatively accurate, I take them as my reference for calculating the coefficients of deformations $\varepsilon_{\phi t}, \varepsilon_{\theta t}, \varepsilon_{rt}$. It is then simple to solve equations 23, 24, and 25 and to calculate these variables $\varepsilon_{\phi t}, \varepsilon_{\theta t}, \varepsilon_{rt}$. I have along of e_θ (**Figure 4**):

$$\Delta M = \int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r^2 \cdot \sin\phi \cdot \mu(r) \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta$$

$$W_{\theta\eta} = \frac{1}{2\pi} \cdot \int_0^{2\pi} W_\theta \cdot \mathrm{d}\lambda \quad \text{and} \quad \tau_m = \frac{\eta}{W_\theta} \cdot \left(\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r \cdot \mathrm{d}r \cdot \mathrm{d}\phi \right) \cdot v_\theta \cdot t$$

Note that I use the weighted annual average energy for the period $t = T_{earth}$ or 24 hours (a full rotation of the Earth).

In the expression of τ_m the part $\dfrac{W_\theta}{\left(\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r \cdot \mathrm{d}r \cdot \mathrm{d}\phi \right) \cdot v_\theta \cdot t}$ represents the lateral pressure exerted on the plate with mass ΔM, moving at speed v_θ and displacement $v_\theta \cdot t$ where t ranges from 0 to T_{earth} with coordinates $latitude, \Delta\phi, \Delta\theta, R_1, R_2, R_3$ (see equation 19 and following), (without the index t for total,) the total deformation coefficients $\varepsilon_{\theta t}$ become either:

$$\begin{aligned} \varepsilon_\theta &= \frac{\frac{1}{2} \cdot v_\theta^2 \cdot \Delta M \cdot \left(2 + \frac{t_{earth} + t}{\tau_m} \right)}{W_\theta} \\ &= \frac{1}{2} \cdot v_\theta^2 \cdot \Delta M \left[\frac{t_{earth} + t}{\eta} \cdot \frac{1}{\left(\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r \cdot \mathrm{d}r \cdot \mathrm{d}\phi \right) \cdot v_\theta \cdot t} + \frac{2}{W_\theta} \right] \end{aligned} \tag{26}$$

If I replace θ by ϕ or r and the full surface $\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r \cdot \mathrm{d}r \cdot \mathrm{d}\phi$ in equations (26) and following by those dependent on ϕ, θ or r (corresponding to the direction of movement: westward, northward or vertical), I can calculate the three strain coefficients $\varepsilon_\phi, \varepsilon_\theta, \varepsilon_r$. The calculation of the derivative of ε_θ with respect to time t gives us the strain rate $\dfrac{\mathrm{d}\varepsilon_\theta}{\mathrm{d}t}$ or, if I consider W_θ as weakly dependent on time t:

$$\frac{\mathrm{d}\varepsilon_\theta}{\mathrm{d}t} = \frac{1}{2} \cdot v_\theta^2 \cdot \Delta M \left[\frac{t_{earth}}{\eta} \cdot \frac{1}{\left(\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r \cdot \mathrm{d}r \cdot \mathrm{d}\phi \right) \cdot v_\theta \cdot t^2} \right] \tag{27}$$

In (26) and (27) the reference speeds v_ϕ, v_θ, v_r come from experimental GPS data.

Given these values for the strain coefficient and strain rate, I can verify the accuracy of my results with experimental GPS velocity measurements (either absolute or with reference to a hot spot) of the Pacific (PA), Eurasia Union (EU), North America (NA), Australian (AU) and South American (SA) plates. Obviously, it is possible to reverse the calculation and calculate strain coefficients, strain rate $\varepsilon_\phi, \varepsilon_\theta, \varepsilon_r$ and $\frac{d\varepsilon_\phi}{dt}, \frac{d\varepsilon_\theta}{dt}, \frac{d\varepsilon_r}{dt}$, knowing the latitude, density and the absolute GPS speed.

GPS measurements are sufficiently reliable ([28]; NASA GPS Time Series data in the IGS88 reference frame) to highlight an interesting property for the pairs $\tau_{m\phi}, \tau_{m\theta}, \tau_{mr}$ and $\frac{d\varepsilon_\phi}{dt}, \frac{d\varepsilon_\theta}{dt}, \frac{d\varepsilon_r}{dt}$, where:

$$\frac{d\varepsilon_\theta}{dt} \cdot \tau_{m\theta} \approx constant, \ \frac{d\varepsilon_\phi}{dt} \cdot \tau_{m\phi} \approx constant \ \text{ and } \ \frac{d\varepsilon_r}{dt} \cdot \tau_{mr} \approx constant$$

I will see later how to calculate these constants, which I call k_θ, k_ϕ and k_r and which are useful for the speed calculation of plates, with the relationships (23 to 25).

5.3. Application to Strain Coefficients and Strain Rate

First, I define the notion of the tectonic plate that is used in the following calculations. In general, the size of a plate is established by its coordinates r, ϕ and θ. Length is measured by longitude, width depends on r and ϕ measured by latitude and thickness is a function of R_1 and R_2 measured along the Earth's radius (**Figure 7**). **Figure 11** is a simple representation of a plate:

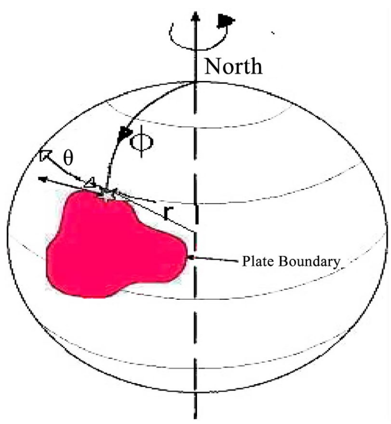

Figure 11. Tectonic plate.

Plates move in three directions, along axes e_ϕ, e_θ, e_r. Several studies of the asthenosphere have shown that the resultant plate velocity is along an axis from east to west [7] [29]-[36]. Thus, the forces exerted by the action of the Sun on the plate masses ΔM depend on their position $\Delta\theta$ on the plate and masses ΔM will be subject to the sum of the pressures exerted by the masses which precedes it from east to west. Thus, points further west and closer to the equator will experience more stress than those lying to the east and further away from the equator. However, as plates are surrounded by other plates, they are likely to be subject to additional stress from both their neighbors and the Earth's internal activity. The overall direction of movement will be from the west and north (the lateral surface of the Earth's movement) and vertically along the Earth's radius. If I apply the results obtained above by considering the term $\frac{2}{W_\theta}$ of (26) to be negligible, and mass ΔM as equal to:

$\Delta M = \int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r^2 \cdot \sin\phi \cdot \mu(r) \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta$ with $t_{orogenic} = t_{earth}$ I can write the following equation for the strain coefficient and strain rate:

$$\varepsilon_\theta = \frac{1}{2} \cdot v_\theta^2 \cdot \Delta M \left[\frac{t_{earth} + t}{\eta} \cdot \frac{1}{\left(\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r \cdot \mathrm{d}r \cdot \mathrm{d}\phi \right) \cdot v_\theta \cdot t} \right] \tag{28}$$

With $\frac{\mathrm{d}}{\mathrm{d}t}\varepsilon_\theta \approx -\frac{\varepsilon_\theta}{t}$ where t is equal to T_{earth}. I note that in (28), only the value θ of the longitude (in the expression of mass ΔM) provides a consistent change in the calculation of ε_θ and $\frac{\mathrm{d}\varepsilon_\theta}{\mathrm{d}t}$. Thus, in the equation for the mass $\Delta M, \Delta\theta$ is calculated using the longitude of the most eastern plate border as follows (Figure 12):

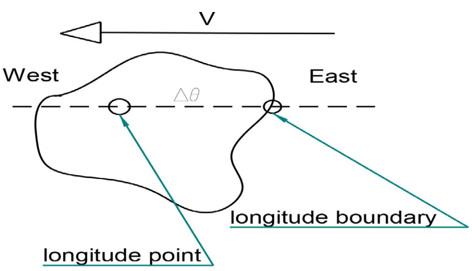

Figure 12. Calculation of $\Delta\theta$.

With lithospheric viscosity η equal to 10^{22} Pa·s along the east-west axis e_θ (see Figure 4), I can draw the following graph for the Pacific plate (PA):

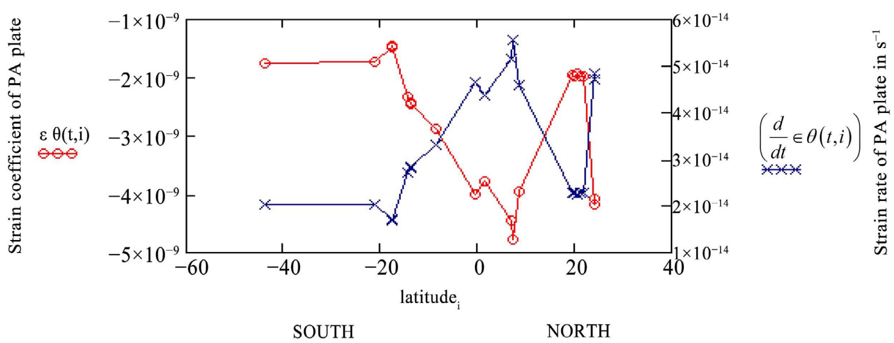

Figure 13. Strain rate and strain coefficient for PA plate.

I used data from GPS velocities to the east and north [28] to plot this curve using the ITRF2000 terrestrial reference system, which is comparable to the ITRF2005 NNR-NUVEL-1A system. $\frac{\mathrm{d}\varepsilon_\theta(t,i)}{\mathrm{d}t}$ represents the strain rate, and ε_θ is the strain coefficient. Obviously, I can do the same calculation along the direction of e_ϕ and e_r (see **Figure 4**) to obtain the three components of the strain rate and strain coefficient for the point in question. I can also represent the graph shown in **Figure 13** for the PA plate as a function of the longitude, and I obtain:

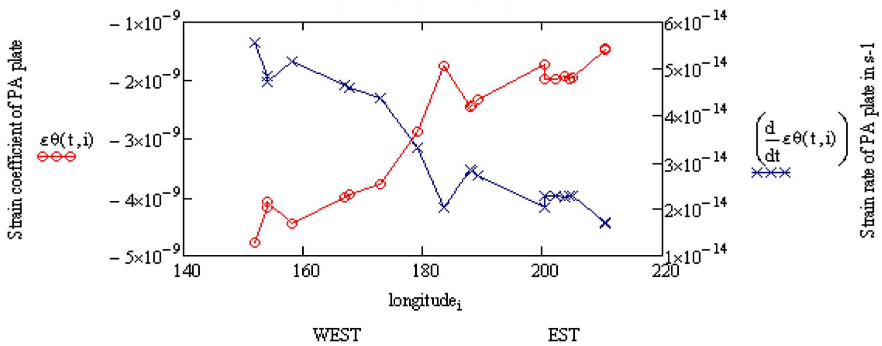

Figure 14. Strain rate and stain coefficient for PA plate.

Again, using the PA plate I can verify the validity of the fundamental relationship $\frac{\mathrm{d}\varepsilon_\theta}{\mathrm{d}t}\cdot\tau_{m\theta} \approx constant = k_\theta$ and, with the expression of $\tau_{m\theta}$ I have:

$$\tau_m = \frac{\eta}{W_\theta}\cdot\left(\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi}\int_{R_1}^{R_2} r\cdot\mathrm{d}r\cdot\mathrm{d}\phi\right)\cdot v_\theta\cdot t \tag{29}$$

This expression, which has been explained above (see also equations 18 and 19). Following the graph of k_θ for the PA plate with the GPS data shown in **Figure 13** and **Figure 14**:

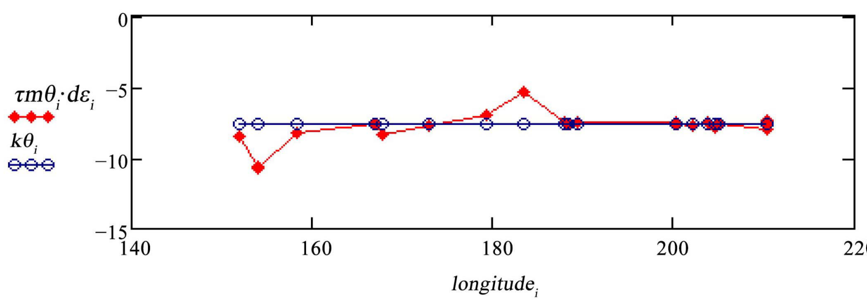

Figure 15. Expression of the constant k_θ for the PA plate.

k_θ (see **Figure 15**) takes the value approximately equal to: 7.54, and I can simplify the equations for the speed of plates (23, 24, 25) taking into account the longitude of the eastern border (or the latitude of the southern border) of the plate in question with the calculation of $\Delta\theta$ or $\Delta\phi$ (see **Figure 12**) as follows:

$$v_\phi = \sqrt{\frac{k_\theta \cdot \frac{2 \cdot T_{earth}}{t_{earth}} \cdot \frac{1}{2\pi} \cdot \int_0^{2\pi} W\phi \cdot \mathrm{d}\lambda}{\int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r^2 \cdot \sin\phi \cdot \mu(r) \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta}} + v_{ref} \quad (30)$$

In this relation t_{earth} is 24h (the time for one rotation of the Earth), t_{earth} is the orogenic time defined above and v_{ref} is a dependent additive speed reference from GPS measurements. k_θ can be calculated from a single GPS speed measurement (V_{GPS}), taken in a stable zone of the tectonic plate. Applying (30) I can write:

$$k_\theta = \frac{-1}{2} \cdot \frac{1}{W_\theta} \cdot \left(\frac{t_{earth}}{t}\right) \cdot V_{GPS}^2 \cdot \int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r^2 \cdot \sin\phi \cdot \mu(r) \cdot \mathrm{d}r \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta \quad (31)$$

5.4. Application of Strain Rate to Calculate the Viscosity of the Asthenosphere

Given GPS speed measurements, I can also calculate the viscosity of the asthenosphere. The principle of laminar flow at low speed gives the graph (Figure 16):

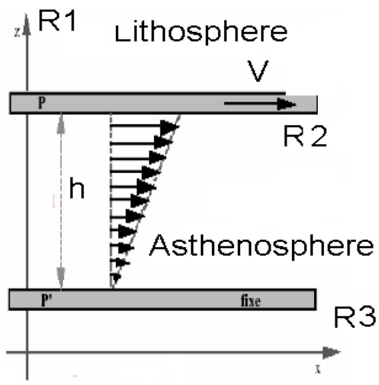

Figure 16. Laminar flow.

Given a constant force F, I can write the following:

$$F = \eta_{asthe} \cdot S \cdot \frac{\mathrm{d}v}{\mathrm{d}h}$$

$$\text{with } S = \int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi} R_2^2 \cdot \sin\phi \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta \quad (32)$$

$$\text{and } \frac{\mathrm{d}v}{\mathrm{d}h} = \frac{PA_{i,1}}{T_{Earthsun}} \cdot \frac{1}{\Delta r}$$

Finally, given (17) and (29) and with η as the viscosity of the lithosphere, I obtain the following:

$$\eta_{asthe} = \eta \cdot \frac{\frac{\mathrm{d}\varepsilon_\theta}{\mathrm{d}t} \cdot \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r \cdot \mathrm{d}r \cdot \mathrm{d}\phi}{\int_0^{\Delta\theta} \int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi} R_2^2 \cdot \sin\phi \cdot \mathrm{d}\phi \cdot \mathrm{d}\theta \cdot \frac{PA_{i,1}}{T_{Earthsun}} \cdot \frac{1}{\Delta R}} \quad (33)$$

In (33) $\Delta R = R_3 - R_2$, R_3 represents the distance between the boundary of the lithosphere and a given point in the asthenosphere, R_2 represents the thickness of the lithosphere. R_1 is comparable to the radius of the Earth (r_{earth}, see Figure 7). $PA_{i,1}$ represents the movement of a GPS position of the PA plate in one year [28] based on the parameters of the point in question (r, ϕ and θ). $\frac{PA_{i,1}}{T_{earthsun}}$ is the speed, where $T_{earthsun}$ is the time for one revolution of the Earth around the Sun. From (40) and assuming that the distance between the bottom of the lithosphere and the asthenosphere ranges from 10 to 2000 km I can draw the following graph with the viscosity of $\eta_{asthenosphere}$ in Pa·s (Figure 17):

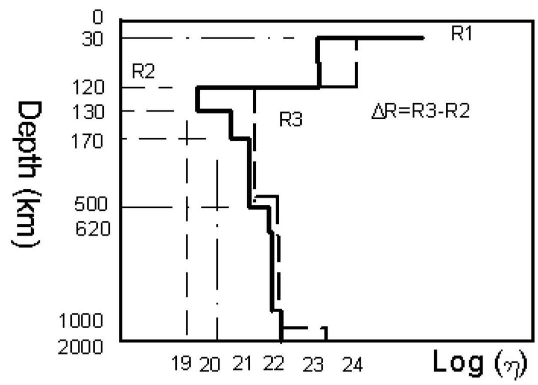

Figure 17. Viscosity (Pas) of the upper mantle dashed line [27].

I can then develop (30). And by replacing $\frac{d\varepsilon_\theta}{dt}$ defined in (28) I obtain the following:

$$\eta_{asthe} = \frac{\frac{1}{2} \cdot \int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} \int_{R_1}^{R_2} r^2 \cdot \sin\phi \cdot \mu(r) \cdot dr \cdot d\phi \cdot \left(\frac{t_{earth}}{t^2}\right)}{\frac{1}{\Delta R} \cdot \int_{\phi(latitude)}^{\phi(latitude)+\Delta\varphi} R_2^2 \cdot \sin\phi \cdot d\phi}$$

This can be simplified as follows, where $t = T_{earth} = 24\text{ h}$:

$$\eta_{asthe} = \frac{t_{earth} \cdot \mu_{earth}}{T_{earth}^2} \cdot \frac{0.415 \cdot (R_3 - R_2) \cdot (R_2^3 - R_1^3)}{6 \cdot R_2^2} \quad (34)$$

This equation does not depend on latitude and longitude. Therefore, the viscosity of the upper mantle of the Earth should be constant for a given depth and for probably old and stable plates. In these calculations I assume:

$R_1 = r_{earth}$, $R_2 = r_{earth} - 120\text{ km}$ and $R_3 - R_2 = \Delta R$ and $\mu_{earth} = 5.5 \times 10^3\ \text{kg} \cdot \text{m}^{-3}$

This does not take into account the Earth's internal forces, or the action of the planets and the Moon, which together make up less than 2% of the total action of the Sun [10]. Nevertheless, together they may make plate movements more complex and further work will be needed to fully understand their contribution.

5.5. Application to Lithosphere Movements

In the preceding section I examined the known speed of plates determined by GPS measurements on the ground. These sources are fairly reliable and are based on international ITRF 2000 and ITRF 2005 systems and the NASA Time Series GPS data in the IGS88 reference frame. In the following, I apply my results to the calculation of the speed of plates over the asthenosphere and show that my theoretical results correspond well to GPS data.

The Earth is subject to Newton gravitation from the Sun, Moon and other celestial bodies. The Sun and the Moon are the nearest and dominant masses, and they exert a force on all infinitesimal terrestrial masses $\mathrm{d}m$. These forces are largely balanced by centrifugal forces due to rotation around a common center of mass for the Earth-Sun and Earth-Moon pairs. I know that lunar and solar tides (relatively lower than that of the moon), deform the surface of the Earth and they generate around 0.1 TW of energy, which is relatively low compared to the 47 TW of terrestrial heat flow.

In the first part of this article, I showed that there was another force acting on infinitesimal masses $\mathrm{d}m$ and that this force depends on the speed of rotation of the Earth without any centrifugal (or other) compensation. From the calculation of the instantaneous energy in (11) and (12) I see that it is much higher than that of Newton gravitation, and the action of the Sun is greater than that of the Moon and planets combined. Nevertheless, the action of the Moon and other planets on plate movements is not negligible (about 2% of the total energy), and this force could be the subject of further work.

According to (9) and (15), during a complete rotation, the total energy W absorbed by the Earth along the Sun-Earth axis takes the following values (for θ from 0 to 2π and ϕ from 0 to π):

$$W_t = \frac{1}{T_{earth}} \cdot \frac{1}{2\pi} \cdot \int_0^{2\pi} W \cdot \mathrm{d}\lambda = 55.53\ \mathrm{TW}$$

The energy dissipated in the Earth far exceeds that of the lunar and solar tides. As described above, I consider that the lithosphere is a rigid and deformable material while the asthenosphere is a ductile material. Thus, in the e_r, e_θ and e_ϕ directions the energy W, will behave as the work of a force on a solid foundation for the lithosphere, but be absorbed and converted into heat in the asthenosphere. Although this is a simplified model, it nevertheless allows a first degree of approximation and a credible solution. I applied my results to the PA, NA, AU, SA and EU plates in the international terrestrial reference frames ITRF 2000 and ITRF 2005, based on measurements from GPS stations ([28]; NASA GPS Time Series data in the IGS88 reference frame). In my model, the forces applied to a particular lithosphere plate depend on the latitude, longitude and distance r to the center of the Earth from the point in question. The values of $\Delta\theta$ and $\Delta\phi$ that are used in the calculation of the strain rate and plate speed must be set as accurately as possible.

As explained above, these forces depend on the eastern (for $\Delta\theta$) and southern (for $\Delta\phi$) plate boundaries. The following is an example of data for the PA plate:

$$\phi(latitude) = \pi \cdot \frac{90 - latitude}{180} \quad \text{and}$$

$$R_1 = R_{earth} \text{ and } R_2 = R_{earth} - 100\ \mathrm{km} \text{ and } \Delta\theta, \Delta\phi$$

Next, I apply (30) for westward speeds, replace θ by ϕ and the full surface $\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi}\int_{R_1}^{R_2} r\cdot \mathrm{d}r\cdot \mathrm{d}\phi$ by $\int_{0}^{\Delta\theta}\int_{R_1}^{R_2} r\cdot \mathrm{d}r\cdot \mathrm{d}\theta$, which represents the external surface subject to pressure toward the north in Equation (26) and following, I obtain Figure 18(a), Figure 18(b), Figures 19(a)-(c) for the PA plate:

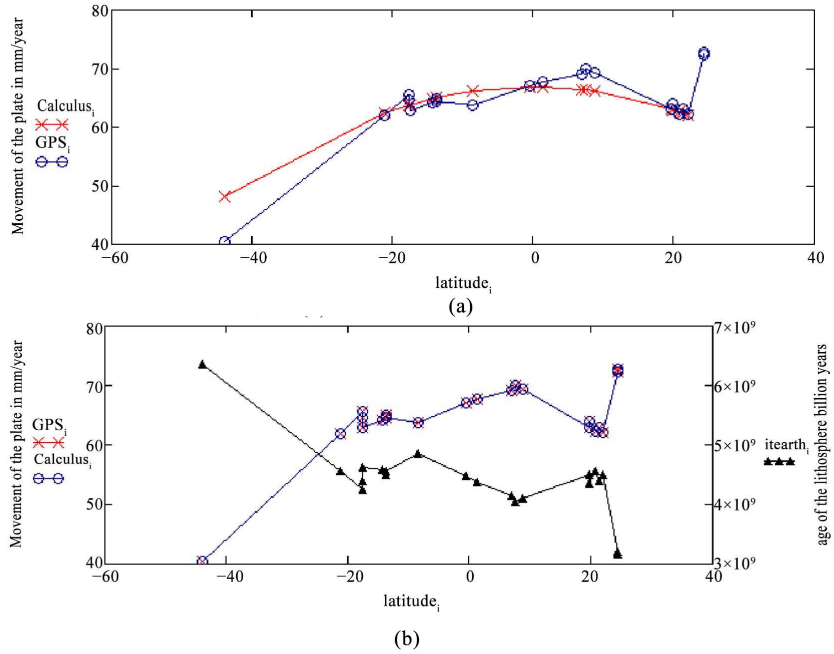

Figure 18. Westward movement of the PA plate.

Figure 18(a) and Figure 18(b) show the westward speed of the PA plate. In this case the results do not closely match GPS data. This is because westward speed is not dependent on $\Delta\theta$, unlike, $\Delta\phi$ which is north-dependent. However, Figure 18(b) shows the results if I hypothesize that orogenic time t_{earth} varies according to longitude and latitude. This graph is very similar to GPS data. Figure 18(b) deserves a thorough analysis as it shows that the age of the place where GPS lithosphere measurements are taken influences the calculation.

Although I could develop graphs based on longitude, it makes no difference to the accuracy of my calculations. In either case the calculations towards the west and north, k_θ and k_ϕ are equal to 7.544 (see Equation (41)).

Figure 19(a) shows Calculus of the speed northward, varying with the position of the southern boundary of the PA plate located at an average latitude of 60˚S, which does not take into account the interpenetration of the AU and PA plates. Figure 19(b) shows the influence of the AU plate on the southern border of the PA plate, which is closer to GPS measurements. Figure 19(b) is an adjustment of curve 19A, and Figure 19(c) is a modification of the masses of the moving portion of the plate, which is a function of $\Delta\theta$ and $\Delta\phi$ and indicates that the action of the AU plate on the PA plate is not uniform along their shared northern and southern borders. It is likely that there is a mini-plate at latitudes of 19 - 25˚S and longitudes of 160˚E - 153˚E. Given that the mass that creates energy $W_\phi = W_\eta$ is greater than the movement of the PA plate, it seems that some energy is transferred to another plate or to the formation of volcanoes and mountains. As not all GPS data points are available, it is quite possible that this plate is much larger. For longitudes 183˚E to 160˚W the masses creating energy $W_\phi = W_\eta$ are lower than the moving mass, indicating that there is energy input from another plate or sources internal to the asthenosphere. Finally, for longitudes 150˚E - 183˚E small masses create small energies $W_\phi = W_\eta$. This data suggest that the AU plate creates a discontinuity in the propagation of pressure from south to north in the PA plate.

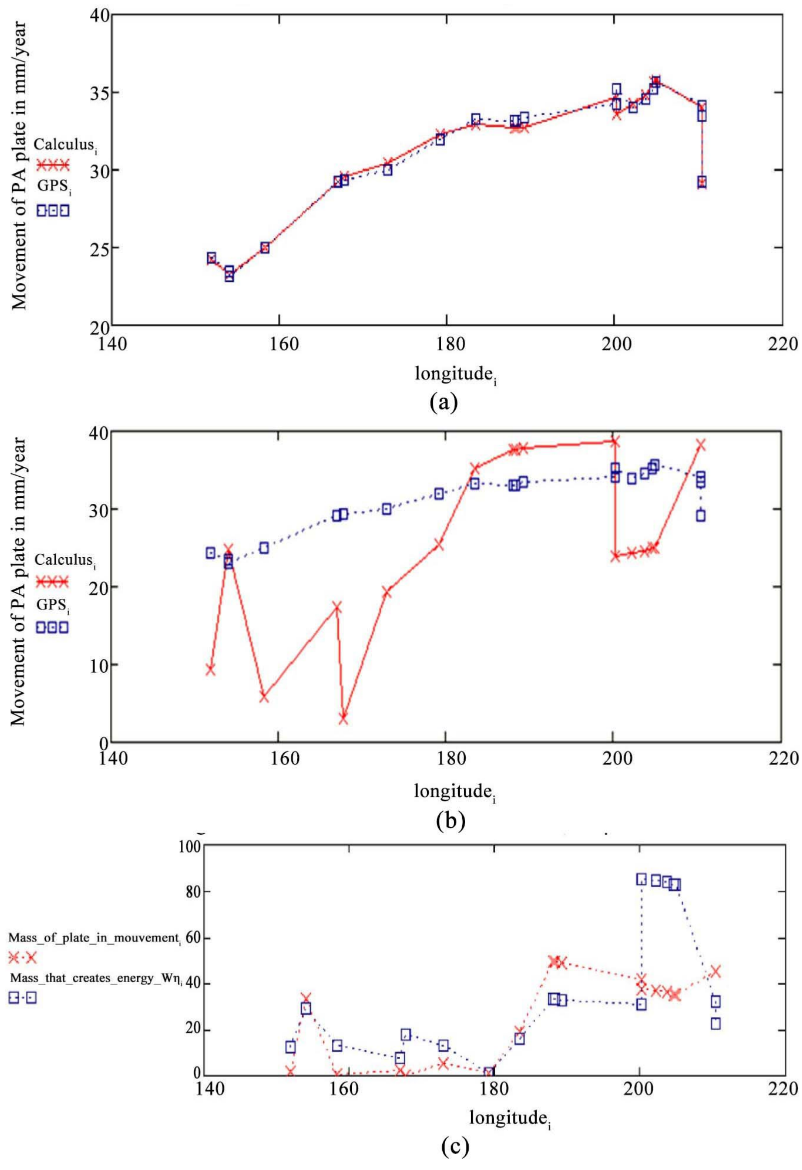

Figure 19. (a) Movement of the PA plate with fixed boundary; (b) Movement of the PA plate with modified Mass; (c) Plate PA, Mass that creates energy W_η and Mass Northward.

A better comparison of the mutual action of the PA and AU plates is found by plotting graphs for the AU plate.

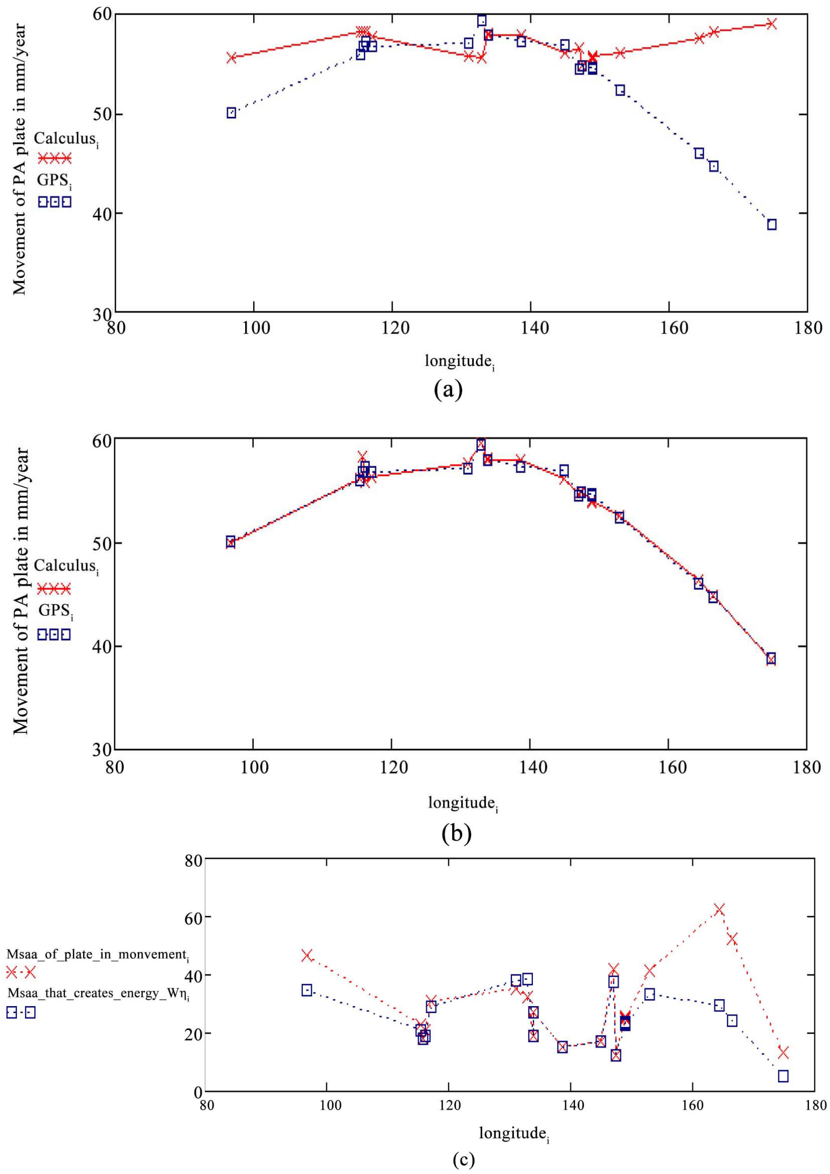

Figure 20. (a) Movement of the AU plate with fixed boundary latitude; (b) Movement of the AU plate with modified Mass; (c) Plate AU, Mass that creates energy W_η and mass Northward.

I can compare the **Figure 19(c)** and **Figure 20(c)** to the interpretation given above. If I compare the portion of the AU plate at longitude 150˚E - 175˚E with the portion of the PA plate at the same longitude (**Figure 19(c)**), I see that they are complementary; the PA plate has part of the energy of the AU plate and energy is transmitted from the south of the PA plate.

Thus, the position of plate boundaries together with theoretical results (adjusted for orogenic or lithospheric age and mass) provides new information about the movements, stress and other activity of the lithosphere and upper mantle of the Earth. Further, more detailed studies will be needed to fully analyze all the results obtained.

The same calculations could be applied to the NA, EU and SA plates. I expect to find similar, detailed results and rich predictive analyses.

Finally, I calculated the west and north speed, using the same projection of energy W along the vector r. Using (30), and replacing θ by r and the surface $\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi}\int_{R_1}^{R_2} r\cdot \mathrm{d}r\cdot \mathrm{d}\phi$ by $\int_0^{\Delta\theta}\int_{\phi(latitude)}^{\phi(latitude)+\Delta\phi} r^2\cdot\sin\phi\cdot \mathrm{d}\phi\cdot \mathrm{d}\theta$ (this integral represents the output surface of the vertical pressure; Equation (26) and following), to calculate the vertical velocity of the lithosphere, I have the following graph (**Figure 21**):

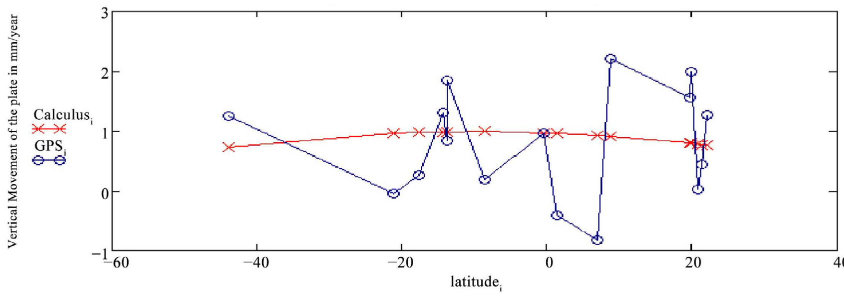

Figure 21. Vertical movement of the PA plate.

This graph is obtained by considering the general equation (30) to be valid for the calculation of the vertical velocity; I replace θ by r Although k_r is different to the lateral velocity and equal to 0.002, it can be easily calculated from a single, stable GPS measurement, in a stable place of tectonic plate (see equation 31). In this case, the gravitational pressure on the mass in question opposes the vertical movement. Energy W_η offsets this inverse gravitational energy and creates slight plate movement.

6. Conclusions

In this article, I have shown how the action of the Sun on the moving masses of the Earth and the planets in the Solar System could give rise to two types of reactions: warming by energy dissipation and tectonic plate movements. I first determined the reduced heat flow Q_o (see Equation (14)) as energy dissipation W_t in the upper mantle. A constant C_t represents q_o, which is of the order of 12 mW/m^2. As this is very low compared to energy W_θ, W_ϕ and W_r, it is not thought to be involved in plate movement calculations. Our reduced heat flow Q_o is largely positive and corresponds to results from other authors [12]. The study of reduced heat flow provided the conditions for the production of heat in environments such as the ductile asthenosphere and pressure in the rigid environment of the lithosphere (comprising the crust). I note that the lithosphere is conducting the heat generated within it as well as that produced in the asthenosphere through the dissipassions of the reaction energy W_t and W_η. I defined four types of reaction relationship; W_t for heat and reduced heat flow calculations, W_θ, W_ϕ and W_r for general calculations of terrestrial heat and plate movements, strain rate and strain coefficients, denoted $\frac{\mathrm{d}\varepsilon}{\mathrm{d}t}$ and ε respectively. This was made possible by considering a symmetric relationship between viscous and elastic behavior (see Equations (17) and (18)) in the upper mantle and the energy produced by the solar reaction on the moving masses of the Earth (see Equation (9)). These equations enabled us to make accurate calculations based on GPS velocities in the ITRF Reference Series 2000, 2005 and NASA data in the IGS88 system. I applied these results and calculated the weighted average viscosity of the asthenosphere. My conclusion was that viscosity (of the asthenosphere) was not dependent on location but only the thickness of the lithosphere and the depth of the upper mantle (see Equations (32)-(34)).

The important question relates to the dynamics of tectonic plates; specifically, how to represent the kinetic energy of plate movements? I resolved this question using the basic equation describing the behavior of the Earth's mantle based on W_θ, W_ϕ and W_r and Equations (17)-(20). These equations made it possible to define the relationship between the total energy of the reaction W_θ, W_ϕ and W_r (equivalent to W_η) and the kinetic energy of the plates W_σ in terms of an equivalence Equation (22). These equivalences model the whole relationship and give the speed of plates. In (30) $k\theta$ represents the product $\varepsilon_t \cdot \tau_m$, which can be calculated from a GPS speed in a stable environment. The application of (30) allowed us to calculate the speeds of the PA, NA, AU, EU and SA plates. In particular, I provide a new analysis of the AU-PA inter-plate influences (**Figure 19(c)** and **Figure 20(c)**). Furthermore, the action of the Sun on the rotating masses of the planets and the Earth will lead to many more results that can be integrated into current knowledge. Finally, my work shows that the Earth's heat is not only due to internal events, whether primitive or radioactive, but also depends on surrounding celestial bodies, particularly the Sun.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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