A tide loading driving for plate motion

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Abstract A significant progress in the geophysics field in the last century is the confirmation of plate motion. But the force behind this motion remains unknown so far, regardless of the continuous efforts by scientific community. Here we propose, the daily tide loading yields a liquid pressure onto continental slope via ocean water, this pressure further contributes a horizontal force to push continent's side and thus move continent and the plate it sites on. The resultant horizontal force based on ideal parameters determines a motion of 39.72, 48.98, and 53.26 mm/year respectively for African, Indian, and Australian plate, and a rotation of $6.84*10^{-9}$ rad/year for American plate.

From 20th century to the first decade of 21st century, a large body of evidences had been concentrated onto a fact that earth's continents (plates) are moving. Around the continents these clues include shape fitting of Africa and South America, coal belt crossed from North American to Eurasian, identical direction of ice sheet of southern Africa and India, and motion measured by global positioning system (GPS). In the oceans the determination of rock age and the discovery of paleomagnetic reversals also support plate motion. Unfortunately, the driving force behind this motion still remains mysterious, regardless of the long-term efforts by scientists. The origin of plate motion may track back to the problem of the Himalayas when geologists made efforts for an answer of how the remains of some tiny sea organisms could exist at the top of this mountain. This resulted in the contraction theory, which believes that a wrinkling process of earth's surface forced the Himalayas to rise up. Wegener proposed the centrifugal and tidal force to be responsible for continental shift (Wegener, 1915). These forces were latterly found to be too weak to work. In addition to this, these forces are so systematic that they could uniformly exert effect on the landmass, the result will not be a split of the landmass but a concentration towards equator. When these attempts failed, people turn their eyes to the interior of the earth. This lead the mantle convention theory (Holmes, 1931) to grow up in the following decades of years. The mantle convention theory addresses that the mantle currents by providing friction (basal drag) between the convection currents in the asthenosphere and the more rigid overlying lithosphere, and the subducting plates by providing a downward pull on plates in subduction zones at ocean trenches, work together to move plates. However, these views of mantle currents are encountering with a big difficulty in both observation and theory. First, some improved techniques based on 3D seismic tomography still failed to find the so-called large scale convection. Especially, some had began to seriously discuss the existence of the mantle current since the first decades of 21st. Second, since the continents initially stayed together as a landmass, the mantle flows would entrain landmass by basal friction to integrally move if the scale of convention is large, a result is no split to produce pieces of continents. Third, the

basal drag, like a conveyor, would continuously transport new crusts from ocean-mid ridges, if there is no vanishing of old crusts, the transferring crusts will pile up in the road. The crowding may block and eventually terminate the transferring. The subduction of Nazca Plate into South American Plate may be a representative of such vanishing, but the majority of the moving plates (like North American Plate and Eurasian Plate) don't hold any clue of subducting or being subducted. Fourth, the mantle convention requires the plates to be separated along the positions of ocean-mid ridges. However, African Plate, Indian Plate, and Australian Plate are moving together along a direction of from southwest to northeast. Fourth, from the view of the distribution of ocean-mid ridges and the direction of plate motion, the mantle flows is very difficult in controlling such a layout. Last, as the mantle currents are entirely hidden in the interior of the earth, it cannot provide a visual dynamics for people to track plate motion. We therefore feel, before the mantle convention theory is put forward further, these problems must be cleared out. Notwithstanding, this work doesn't intend to deal these problems, instead, get back to the exterior of the earth to find a possible solution.

Recently, tide is redefined as a result of the oscillation of ocean basin that originated from the daily rotation of deformed earth. This provides new line for us to consider plate motion. Practically, the total pressure a liquid bears includes static and dynamic pressure. The dynamic pressure is related to the liquid's motion, while the static pressure is exerted by the liquid equally in all directions. In most of coasts, a tide experience two cycles of high and low water during a day (nearly 24 hours). Tide range is usually limited to a few meters, this means that the speed of tide loading is considerably low. And then, the dynamic pressure of a tide may be neglected. The daily tide loading around continent yields a static pressure. This pressure, via ocean water, may contribute a horizontal force to push continent's side. As shown in Figure 1, tide loading yields pressure F_1 (F_2) that is always vertical to continent's slope, this pressure contributes a horizontal force $F_1'(F_2')$ towards continent's side. We assumed ocean depth to be equal anywhere, and then, the combined force a plate holds may be expressed with $(F_1'-F_2'-f)$, where $F_1'=0.5\rho_{water}gL[h_1(2h+h_1)]$, $F_2'=0.5\rho_{water}gL[h_2(2h+h_2)]$, F_1 are F_2 are the resultant horizontal force from tide loading respectively at right side and at left side of continent; f denotes friction force from basal drag between mantle and crust and from resistance between adjacent plates; ρ_{water} , g, L, h_1 , h_2 , and h respectively denotes density of water, gravitational acceleration, width of ocean water, height (range) of tide at right side of continent, height (range) of tide at left side, and ocean depth. We see, the resultant horizontal force is irrelative to the inclination of continental slope. A simple estimation based on the expression above is that a tide loading of volume 1.0 m^3 (1*1*1, length, width, and height) onto an ocean of 3,000.0 m depth may yield a horizontal force of 29,404,900.0 N, although this volume of tide loading owns only a gravity of 9,800.0 N.



Fig. 1. Modelling the horizontally normal force resulted from tide loading at continent's sides. Yellow arrow denotes the horizontal force contributed by the pressure (red arrow) from tide loading, green arrow denotes basal friction.

Tides are extensively distributed around the coasts of continents, but tide ranges are different from one coast to another (Figure 2). It is the inequality of the resultant horizontal forces between the coasts of continents to move plate, since continent and crust are physically connected together.



Fig. 2. A global view of the distribution of tidal pattern, tidal range, plate tectonics, and the resultant horizontally forces from tide loading. Tide data supporting is from U.S. NOAA, GLOSS database - University of Hawaii Sea Level Center (Caldwell et al. 2015), and Bureau National Operations Centre (BNOC) of Australia, and tide range also refer to the times atlas of the oceans, 1983, Van Nostrand Reinhold, NY.

Most of the coasts of continents undergo two high and two low waters per day, these fit to two loadings and two unloadings of tide, each tide loading (unloading) would take a time of almost 6 hours. For each continent, tide loading (unloading) is impossible to be synchronous at its every site, but this will not affect the resultant horizontal force to be generated and to work. Therefore, we may approximate all tide loadings (unloading) around the coasts of continents to occur at identical time. Practically, the rate of tide loading is nonlinear, the resultant horizontal force will not vary uniformly, this makes us difficult to determine the time that the plate takes to accelerate or decelerate during a day. Here we approximate this rate of tide loading to be linear. Refer to Figure 3, we assumed the lowest water of tide loading to be reference level that yields no horizontal force to continent's side. With the passage of time, the resultant horizontal force (F) begins to increase, but the plate that bears this force will not move until this force is greater than friction (f) at the time t_1 . Once F > f, this gives acceleration (a) to move plate. With the advent of the highest water of tide loading, the horizontal force reaches its maximal, which also corresponds to a maximum of acceleration. After this moment, tide begins to unload, the horizontal force gradually decreases, the speed of plate motion continues to increase until F=f at the time t_2 . Subsequently, plate motion begins to decelerate when $F \le f$, and eventually terminates at the time t₃. As a linear tide loading yields a linear horizontal force, it therefore will be the matter of $t_2-t_1=t_3-t_2$. If friction (f) is further given, the time that the plate takes to accelerate or decelerate may be got. With these assumptions, the displacement a plate accepts during a year may be roughly written as



Fig. 3. Dynamic analysis of plate motion based on tide loading. Stage $t_1 \sim t_3$ and $t_4 \sim t_6$ denote the time that the plate take to move under the combined force during a day.

$$D = 0.5a^* \Delta t^2 * 2^* 365 \tag{1}$$

a=(F-f)/M

Where 0.5*a*, Δt , 2, and 365 denote respectively the average acceleration, the time that the plate takes to accelerate during a tide loading, the number of tide loading per day, and the number of day during a year; *a* denotes the acceleration that the plate holds at the time of the highest water of tide loading, (*F-f*) denotes the combined force that the plate bears, and *M* denotes plate's mass, which may be further expressed as $M=Sd\rho_{plate}$, *S*, d, and ρ_{plate} are respectively plate's area, thickness, and density. Δt may be further expressed as $\Delta t=(1-f/F)*12$, and 12 denotes time length of a tide of both loading and unloading.

Some of plates (American Plate and Eurasian Plate, for instance) perform some kind of rotation that looks like around a fixed point rather than wholly transfer. This motion may be expressed with

$$D' = \omega R'$$
 (2)
 $\omega = 0.5 \Theta * \Delta t^2 * 2 * 365$
 $Fr = 0.5 M * R^2 \Theta$

where Fr denotes torque, F and r are respectively the combined horizontal force and the distance applied by this force; $0.5M^*R^2$ and Θ denote respectively moment of inertia and angular acceleration when plate's mass is assumed to be uniformly distributed onto a disc of radius R; ω denotes the angular rotation that the plate (ideal disc) accepts during a year; D' denotes the linear displacement that the plate accepts at a distance of R' with respect to the fixed point.

With these theoretical ideas, we evaluated the motion of African, Indian, Australian, and American plate (Figure 4). The basic information of these plates, the resultant horizontal forces or torques exerted on them, and the accepted motions are respectively listed in Table 1, 2, and 3. Finally, African, Indian, and Australian plate respectively hold a motion of 39.72, 48.98, and 53.26 mm/year, American plate performs a rotation of 6.84*10⁻⁹ rad/year, which corresponds to a motion of 34.20 mm/years at a distance of 5,000 km relative to the assumed fixed point.







 F_4

60°S



Fig. 4. Geographic treatment of the controlling sites around four selected plates and the resultant normal forces exerted on them. F (yellow arrow) denotes the horizontal force, while purple bar denotes the distance applied by this force. D2, a ideal disc that represents a mean mass distribution of north and south plate. O denotes the fixed point that the plate rotates on.

Plate	Area (S)	Thickness (d)	Density (p _{plate})	Mass (<i>M</i>)		Site		Distanc to sit	e of site te (<i>L</i>)	Tide range (Δh)	Ocean water depth (<i>h</i>)
	km ²	km	kg/m ³	kg	Num.	Longitude	Latitude	k	m	m	m
					0	$70^{\circ}W$	30°N	0_5	3,367		
					1	$20^{\circ}W$	73°N	0_6	6,005		3,500
					2	$84^{\circ}W$	33°N	1_2	5,609		
					3	130°W	55°N				
					4	95°W	$17^{\circ}N$	3_4	5,167		
A .	110 500 000	57	2 100	2.075 . 22	5	90°W	3°N	3°N 5_11 3	3623	2.0	
American	119,500,000	56	3,100	2.07E+22	6	$70^{\circ}W$	24°S			3.0	
					7	90°W	55°S	10_7	7,574		
					8	67°W	43°S	8_9	4,914		
					9	37°W	7.5°S	9_10	4,191		
					10	$70^{\circ}W$	11°N				
					11	$60^{\circ}W$	$10^{\circ}S$				
					12	6°W	35.5°N				
					13	$17^{\circ}W$	14.7°N	12_13	2,535		
					14	$7^{\rm o}{ m W}$	4.6°N	13_14	1,531		
	(1.200.000		2 1 0 0	1.0(1).00	15	80E	4.4°N	14_15	1,696	•	3,500
African	61,300,000	56	3,100	1.06E+22	16	22.2°E	34.7°S	15_16	4,577	2.0	
					17	30.4°E	30.7oS	16_17	886		
					18	$40^{\circ}E$	16°S	17_18	1,904		
					19	51°E	11°N	18_19	3,237		

Table 1 Basic information for plates

					20	66 8ºE	25°N				
					20	00.0 L	25 1				
					21	77.5°E	8°N	20_21	2,205		
Indian	11,900,000	56	3,100	2.07E+21	22	80°E	15.2°N	21_22	846	4.0	3,500
					23	91.5°E	22.7°N	22_23	1,468		
					24	94.3°E	16°N	23_24	801		
					25	114°E	23°S	25_31	2,162		
					26	117.2°E	35°S	25_26	1,370		
					27	131°E	31.5°S	26_27	1,340		
					28	149.8°E	37.6°S	27_28	1,846		
Australian	47,000,000	56	3,100	8.16E+21	29	153°E	25.4°S	28_29	1,390	3.0	3,500
					30	142.4°E	10.8°S	29_30	1,970		
					31	131°E	12.2°S	30_31	1,252		
					32	133.7°E	3.5°S				
					33	150°E	10.5°S	32_33	1,959		

Note: all geographic sites and resultant distances refer to Figure 4.

Plate			Horizonta	lly normal force N	e (F)		Friction	Friction (f)	Combined force (<i>F-f</i>)	Linear acceleration (<i>a</i>)	Time for acceleration during a tide loading (Δt)	Displacement (D)
			Contribution to East (+), West (-)	Contribution to North (+), South (-)	Sum	Inclination of composition to East (°)	(ζ)	N	Ν	m·s ^{−2}	hour	mm/year
	F_6	1.74E+14	1.54E+14	-8.1E+13								
	F_7	1.05E+14	7.43E+13	7.43E+13								
	F_8	1.16E+14	7.74E+12	1.16E+14								
African	F9	3.14E+14	2.96E+14	1.06E+14								
	F_{10}	6.08E+13	-2.7E+13	5.47E+13								
	F_{11}	1.31E+14	-1.1E+14	7.14E+13								
	F ₁₂	2.22E+14	-2.1E+14	8.38E+13								
			1.9E+14	4.26E+14	4.66E+14	69.96	0.989	4.61E+14	5.13E+12	4.8184E-10	0.132	39.72
	F ₁₃	3.03E+14	2.56E+14	1.61E+14								
	F_{14}	1.16E+14	-1.1E+14	3.81E+13								
Indian	F ₁₅	2.02E+14	-1.1E+14	1.69E+14								
	F ₁₆	1.1E+14	1.01E+14	4.24E+13								
			1.38E+14	4.11E+14	4.33E+14	71.44	0.993	4.28E+14	3.03E+12	1.4673E-09	0.084	48.98
	F ₂₃	2.23E+14	1.19E+14	-1.9E+14								
Australian	F_{17}	1.41E+14	1.36E+14	3.63E+13								
	F ₁₈	1.38E+14	-3.4E+13	1.34E+14								

Table 2 Horizontally normal forces and resultant motions for African, Indian, and Australian plates

F ₁₉	1.9E+14	5.87E+13	1.81E+14								
F ₂₀	1.43E+14	-1.4E+14	3.63E+13								
F ₂₁	2.03E+14	-1.6E+14	-1.2E+14								
F ₂₂	1.29E+14	1.57E+13	-1.3E+14								
F ₂₄	2.02E+14	7.96E+13	1.85E+14								
		7.31E+13	1.37E+14	1.56E+14	61.99	0.984	1.53E+14	2.49E+12	3.054E-10	0.192	53.26

Note: all forces and distances refer to Figure 4.

Plate	Distance appliHorizontallyby thenormal force (F)horizontallynormal force (F)horizontally		applied he ntally force (<i>r</i>)	Torque (<i>Fr</i>), Left(+), Right(-)	Friction coefficient	Combined torque (Fr)	Moment of inertia (I)	Angular acceleration (O)	Time for acceleration during a tide loading (Δt)	Displacement (D) at $R' = 5000 \text{ km}$		
		Ν	Num. km		N·m	(ζ)	N∙m	$kg \cdot m^2$	rad·s ⁻²	hour	mm/year	
	F_1	5.77E+14	0.5*1_2	2804.5	1.61936E+21							
	F_2	5.32E+14	0.5*3_4	2583.5	-1.3742E+21							
Amorican	F_3	7.8E+14	0_6	6005	4.68209E+21							
American	F_4	5.06E+14	0_5	3367	-1.70326E+21							
	F ₅ 4.31E+14 5_11 3623 -1.5631E+21		-1.5631E+21									
					1.66089E+21	0.982	2.99E+19	9.65E+35	3.0996E-17	0.216	34.2	

 Table 3 Horizontally normal forces and resultant motion for American plate

Note: all forces and distances refer to Figure 4.

The resultant horizontal force from tide loading provide possibility for us to conceptually track the continental shift that Wegener proposed in that era. Tide loading is launched from east to west as the earth spins on its axis, the travelling water (when blocked) will accumulate to form larger tide at the coast. This means the larger tides occur mainly at the east and west sides of continent while the weaker ones occur at the south and north sides of continent. Other experience also shows that the largest tide usually occurs at some concave of coast such as Bay of Fundy (tidal range here may reach 16 meters). The concave actually act as a funnel to amplify tide. Refer to Figure 5, at the time of Upper carboniferous the opening at the east of landmass at first provides convenience for larger tide to load, the resultant horizontal forces then push adjacent continents to move and expand the gap further. The weakness of the resultant horizontal force at the south head of landmass gives little resistance to the resultant horizontal force at the opening. With the passage of time, the landmass was partly split, and finally exhibited the shape at the time of Eocene. This, in turn, provides convenience for more tide to load, and also more horizontal forces to be generated to push continents. The landmass was further split until the advent of older quaternary. At this time the primitive shapes of independent continents were established, the tide loading continued to spread, and the continents also continued to move until present.





Fig. 5. Modeling the evolution of continental shift based on tide loading. Yellow and blue arrows denote respectively the resultant horizontal forces from tide loading and continental shift. Red circles from small to large represent an increasingly expanding of tide loading within the landmass. The background map refers to Wegener's work (1924).

Under the effect of the resultant horizontal force from tide loading, the oceanic crust between American plate and African plate is increasingly tensed by the separation of these two plates. The elastic crust at first endures this tension. But with the passage of time, the tension is gradually accumulated and finally breaks the limitation, a rupture of the oceanic crust temporarily releases the accumulated tension. The erupted magma from mantle is cooled by ocean water to form newly crust at the opening of the rupture, this newly crust in turn welds the gap. The magnetite crystals entrained by the magma are also locked by earth's magnetic field into the newly crust to form a stripe. As tide loading is continuous day after day, the oceanic crust (including newly one) is dragged by continent to move together. With the advancement of plate motion, the tension between the two plates again is accumulated, and finally breaks the limitation of earth's elastic. This leads to a second rupture for the oceanic crust, and further the formation of another newly crust and magnetic stripe. Daily experience shows that the welded site of a material is solid. So, we think, the magnetic stripes found in the oceanic crust represent not only a fact of seafloor spreading (Hess, 1962; Vine and Matthews, 1963) but also a remark that the oceanic crust is always in a state of periodically being ruptured and welded, companied by a concentration of tension and its release. When this point is got, the transform fault (Wilson,1965) in the Atlantic could be a result of the composition of some unparallel and unequal tensions that tear the oceanic crust, as shown in Figure 6.



Fig. 6. Modeling dynamics for the transform fault in the Atlantic. Red arrows denote the resultant horizontal forces from tide loading around continent's side. Yellow arrows represent the combined forces onto the oceanic crust. The background map is based on the floor of the oceans (Remur et al., 1980).

References

Caldwell, P. C., M. A. Merrfield, P. R. Thompson (2015). Sea level measured by tide gauges from global oceans — the Joint Archive for Sea Level holdings (NCEI Accession

0019568), Version 5.5, NOAA National Centers for Environmental Information, Dataset, doi:10.7289/V5V40S7W.

- Hess, H. H. (1962). History Of Ocean Basins, in Engel, A. E. J., James, H. L., & Leonard, B. F., eds. Petrologic Studies: A volume in honor of A. F. Buddington. Boulder, CO, Geological Society of America, 599-620.
- Holmes, Arthur (1931). Radioactivity and Earth Movements. *Transactions of the Geological Society of Glasgow*. Geological Society of Glasgow: 559–606.
- Remur T D, Heezen B C, Tharp M. (1980). The floor of the oceans. Marie Tharp.
- Vine, F. J., & Matthews, D. H. (1963). Magnetic Anomalies Over Oceanic Ridges. *Nature*, 199(4897), 947-949.
- Wegener, A. (1915). The Origin of Continents and Oceans. New York, NY: Courier Dover Publications.
- Wegener, A. (1924). The origin of continents and oceans (Entstehung der Kontinente und Ozeane). Methuen & Co.
- Wilson, J.T. (1965). A new class of faults and their bearing on continental drift. Nature. 207: 343–347.