What Drives the Earth's Plates ?

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Abstract

Plate tectonic theory that comprehensively describes the earth's plate motion and terrestrial features represents one of the most significantly achievements in the past 100 years. However, an indisputable fact around this theory is the force behind plate motion is still unknown. Here we propose, the daily tide loadings around continents yield pressures onto continental slopes, the net effect combined from these pressures pushes the continents to globally move. These moving continents, representing the upper parts of the continental crusts, by means of basal friction, moderately entrain the crusts beneath them and the adjoining oceanic crusts, creating various terrestrial features. Quantitatively estimation shows that tide loadings provide South American, African, Indian, and Australian continents respectively a nearly straight motion of 28.44, 41.11, 55.63, and 61.60 mm/year. A torque effect likely contributes rotation to North American and Eurasian continents.

Introduction

One of the most significantly achivements in the 20th century is the establishment of the plate tectonics theory that developed from the earlier conception of continental shift. The continent shift hypothesized that the continents had moved over the earth's surface in the distant past (Wegener,1915). The supporting evidences for this movement include a shape fitting on the opposed sides of African continent and American continent, coal belt crossed from North American to Eurasian, identical direction of ice sheet of southern Africa and India, and speed measurement by global positioning system (GPS). In addition, the discovery of paleomagnetic reversals in the oceans further consolidated this belief (Hess, 1962; Vine and Matthews, 1963). Nevertheless, the driving force behind this movement is so far unclear, regardless of the unremitting efforts made by scientific communities in the past 100 years. The first to deal the origin of this movement is the contraction theory, which believed a wrinkling process of earth's surface had forced the Himalayas to climb up. Wegener (1915) directly ascribed the continental shift to the centrifugal and tidal forces. These forces were subsequently found to be too weak to work. After these attempts failed, people began to turn their eyes to the interior of the earth. This cultivated the mantle convection theory and lead it to flourish in the following decades (Holmes, 1931; Runcorn, 1962a,b).The mantle convection theory addressed that the mantle currents (by providing 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) work together to move plates. Unfortunately, the mantle convection theory is presently being trapped by much difficulty. First of all, the large scale convection this theory requires still cannot be detected by some improved techniques based on 3D seismic tomography. In fact, the existence of the mantle currents has been extensively suspected since the last decade of the 20^{th} century. Second, the mantle convection theory would require the basal drag (like conveyor) to continuously move the newly formed crusts away from the spreading center, if there were no depletion of older crusts in the front, the transferring crusts would jam in the road, terminating the transportation. The subduction is thought to be a representative of such depletion. However, most of the plates (like North American Plate and Eurasian Plate) don't hold any clue of subduting or being subducted anywhere. Last, also the most important, the diversity of plate motions seriously challenges the mantle currents. This diversity mainly manifests that, some plates (South American, African, Indian, and Australian, for instance) move approximately along straight path, while others (Eurasian, North American, and Antarctic, for instance) move in a rotating way. In particular, the Eurasian Plate rotates clockwise while its adjoining North American Plate rotates counter-clockwise, the Antarctic plate waddles slightly. It is extremely difficult to imagine how the mantle currents exert at the bottom of lithosphere to serve these motions. We feel, before the mantle convection theory is put forward further, these issues should be cleared out. Notwithstanding, this work doesn't intend mending the mantle convention theory, instead, getting back to the exterior of the earth to find a possible solution. Of course, we would moderately demonstrate why the mantle convection theory contradicts with some of observations.

A tide loading driving for plate motion

It's already known that liquid exerts pressure on the sides of the vessel that holds it. Practically, the total pressure a liquid exerts includes static pressure and dynamic pressure. The dynamic pressure is related to the liquid's motion, while the static pressure is exhibited by the liquid equally in all directions. For most of coasts, they experience two cycles of high and low water per day (around 24 hours), that's the tide we are familiar with in everyday life. Tide range is usually no more than a few meters, this means that the speed that the tide loads/unloads is low and that the dynamic pressure a tide exerts may be neglected. The static pressure a tide exerts, however, by means of ocean, may conduct effect to push continent's side. As shown in Figure 1, we assumed that there were no tide loading onto the continent's side, the pressure yielded by the ocean at the left side of the continent would be offset by the pressure yielded by the ocean of same depth at the right side, the excessive pressure yielded by the ocean at the left side would also be offset by the resistance from the oceanic crust at the right, the net result is the continental crust remains in a state of equilibrium. The presence of tide loading, however, breaks up this equilibrium, because the height of tide, which determines the pressure, differs from one coast to another. Tide loading yields the pressure $F_1(F_2)$ that is vertical to the continent's slope, and the pressure $F_1(F_2)$ may be written as

$$F_1=0.5\rho_{water}gL[h_1'(2h_1+h_1')]/\sin\alpha$$

$$F_2=0.5\rho_{water}gL[h_2'(2h_2+h_2')]/\sin\beta$$

where ρ_{water}, g, and L denote respectively density of water, gravitational acceleration, and width of ocean. h_1 and h_2 denotes ocean depth respectively at the right and at the left, h_1' and h_2' denote the range of tide at the two sides. α and β denote the inclination of continent's slope respectively at the right and at the left side.

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 pressure of 29,404,900.0 N onto continent's side if the inclination of the slope is 90^o, even if this volume of tide loading holds only a gravity of 9,800.0 N. The pressure $F_1(F_2)$ can be further decomposed into horizontal force $F_1'(F_2')$ and vertical force $F_1''(F_2'')$. According to the geometry, $F_1' = F_1\sin\alpha = 0.5\rho_{water}gL[h_1'(2h_1+h_1')]$, $F_2' = F_2\sin\beta = 0.5\rho_{water}gL[h_2'(2h_2+h_2')]$, $F_1'' = F_1\cos\alpha = 0.5\rho_{water}gL[h_1'(2h_1+h_1')]\cot\alpha$, $F_2'' = F_2\cos\beta = 0.5\rho_{water}gL[h_2'(2h_2+h_2')]\cot\beta$. For the continental crust, the combined force in the horizontal direction would be $(F_1'-F_2'-f)$, where f denotes basal friction between the upper part of the continental crust and the lower part. Here we term the upper part of the continental crust, which is exerted by tide loading, as continent in the following sections. It is this combined force to drive continent to horizontally move. Once this kind of combined horizontally force is connected to the tide loadings of all coasts, it determines the continents to globally move. Figure 2 exhibits a globally distribution of tide loading and the resultant pressures.

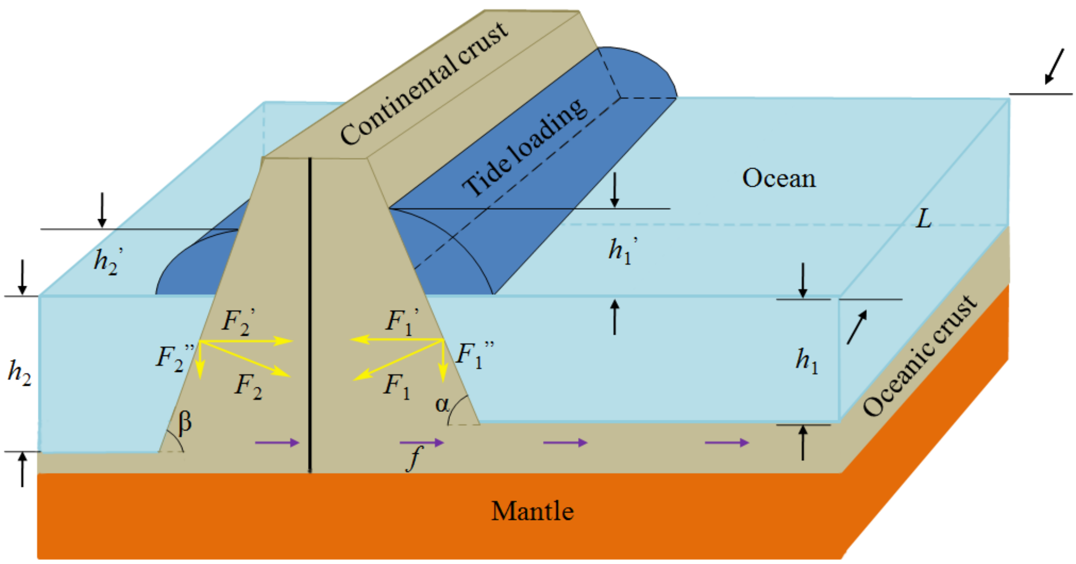

Fig. 1. Modelling the dynamics of the continental crust under the effect of tide loading. $F_1(F_2)$ denotes the pressure exerted by tide loading, while $F_1'(F_2')$ and $F_1''(F_2'')$ denote respectively the horizontal and vertical forces that are decomposed from the pressure. f denotes basal friction between the upper part of the continental crust and the lower part. L denotes width of ocean. h_1 and h_2 denotes ocean depth respectively at the right of the continent and at the left, h_1' and h_2' denote the range of tide loading at the two sides. α and β denote the inclinations of continent's slope at the two sides.

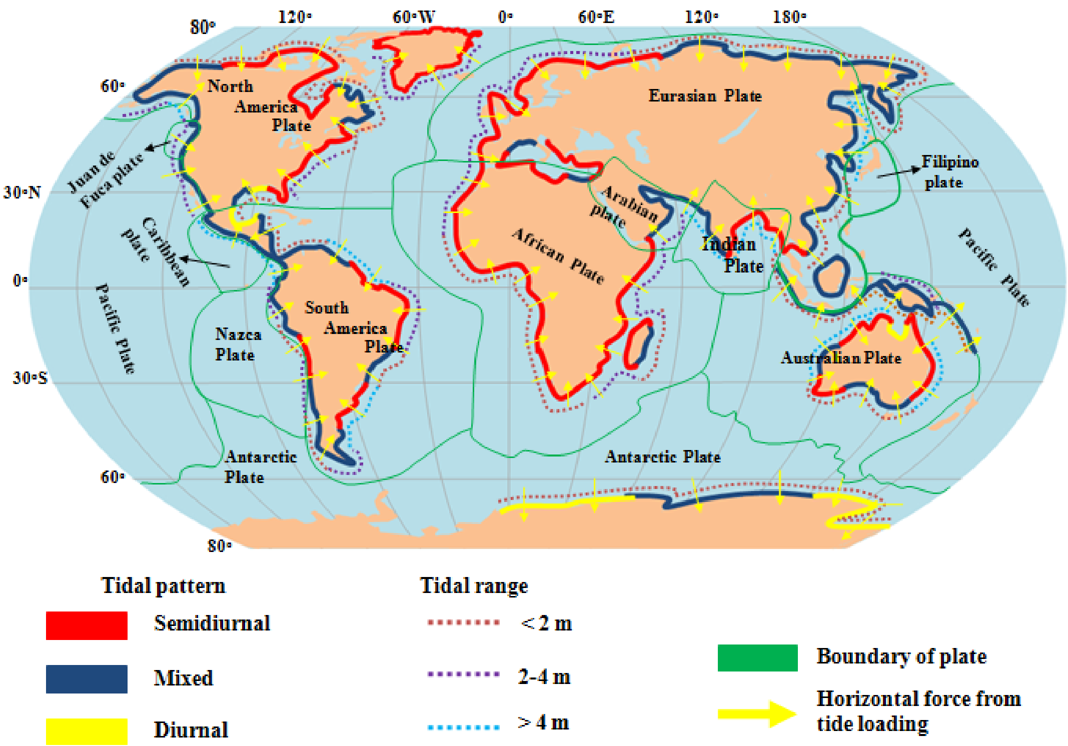

Fig. 2. A global view of the distribution of tidal pattern, tidal range, plate tectonics, and the resultant horizontally forces from tide loading. Tide data supporting is from U.S. NOAA, GLOSS database - University of Hawaii Sea Level Center (Caldwell et al. 2015), and Bureau National Operations Centre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

Most of the coasts undergo two high and two low waters per day, these fit to two loadings and two unloadings of tide, each of these loadings and unloadings would take a time of almost 6 hours. For each continent, tide loading at its every coast is not synchronous, but this wouldn't affect the pressure to be generated and to work further. In addition, the rate of tide loading is not uniform, this leads the pressure generated to vary timely and yields difficulty to determine the time that the continent takes to accelerate or decelerate during a day. Moreover, the range of tide performs two cycles per month that is associated with the positions of the earth, moon, and sun. The range becomes maximal at the times of full and new moon and minimum at the times of first quarter and last quarter. We here assumed the rate of tide loading to be uniform anywhere, all of tide loadings to occur at identical time, and the range of tide loading to be invariable during the month. In appearance, tide looks like a vibration of water. Based on Figure 3, we treat the lowest water level of tide to be the reference level that yields no pressure onto the continent's side and the time of the lowest water level to be a starting point. With the passage of time, the horizontal force (F) increases as the loading of tide accordingly enhances the pressure, but the continent that bears the force will not move until the horizontal force is greater than resistance (f) at the time t_1. Once $F>f$, this yields acceleration (a) to move continent. With the advent of the highest water level of tide, the horizontal force reaches its maximal, which also fits to a maximum of acceleration. After this moment, tide begins to unload (fall), the horizontal force (also the pressure) gradually decreases, but the speed of the continent continues to increase until F=f at the time t_2. Subsequently, the motion begins to decelerate when F<f, and eventually terminates at the time t_3. As the tide loading with uniform rate yields uniform changing pressure, it therefore will be the matter of t_2-t_1=t_3-t_2. If resistance (f) is given, the time that the continent takes to accelerate or decelerate during the day may be got.

Practically, continent is circled by a train of coasts, and each of these coasts connects to one another. This means that the tide loading at each coast yields a horizontal force and that the total horizontal force a continent accepts would be a combination of these horizontal forces yielded at these coasts. The spherical earth mechanically bends continent, this makes the horizontal forces unable to fall onto a plane. We here decompose each of these horizontal forces into latitudinal force and longitudinal force, assumed continent to be both rigid and planar, and further assumed all of the decomposed forces to ideally pass through continent's barycentre. This treatment is to produce a straight motion for the body that bears these forces and to not consume these forces deforming the body. Finally, the total horizontal force is a recombination of the decomposed forces in the latitudinal and longitudinal directions. And then, the displacement a continent accepts during a year may be roughly written as

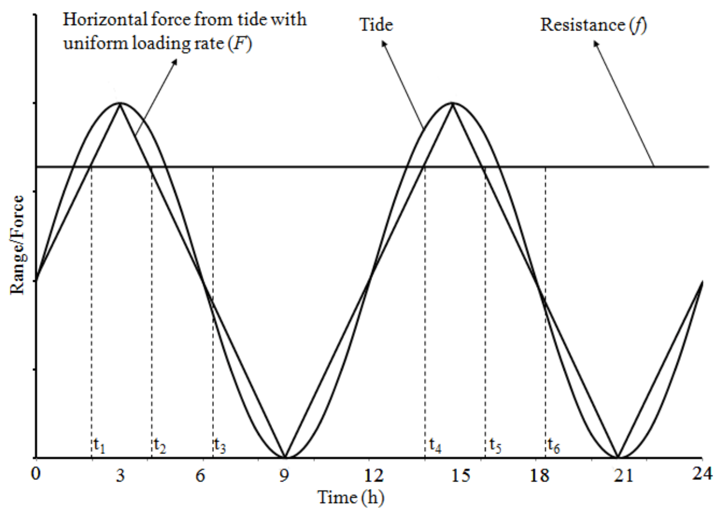

Fig. 3. Dynamic analysis for the continent's motion based on tide loading. Stage t_1~t_3 and t_4~t_6 denote the time that the continent takes to move during a day.

$$D=0.5a*\Delta t^2*2*365 \quad (1)$$

$$a=(F-f)/M$$

Where 0.5a, Δt, 2, and 365 denote respectively the average acceleration, the time that the continent 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 continent holds at the time of the highest water level of tide, F and f are respectively the total horizontal force and the resistance, and (F-f) denotes the combined force in the horizontal direction that the continent finally bears, and M denotes the continent's mass, which can be expressed as M=$Sd\rho_{plate}$, S, d, and ρ_{plate} are respectively the continent's area, thickness, and density. Δt may be written as Δt=(1-*f*/*F*)*12, and 12 denotes time length of a tide of including loading and unloading.

With these theoretical ideas, we estimated the movement of South American, African, Indian, and Australian continents in this work. The determination of the controlling sites of these continents is listed in Figure 4, the horizontal forces exerted and the results are respectively shown in Table 1 and 2. On the whole, these results may be well consistent with observations. It should be kept mind that the assumptions above are only moderate for these four continents. For Eurasian and North American continents, their curvatures cannot be ignored because of large size, moreover, the horizontal forces yielded by tide loading cannot very pass continent's barycentre because of uneven mass distribution, generating torque effect, together with the influence (push, for instance) from adjoining continent, these determine that these two continents get most likely curved motion (rotation) rather than straight one. This work suggests that only a very little part of the pressure yielded by tide loading is used to move the continent, the majority of it serves pulling the crust beneath the continent and the adjoining oceanic crust, forming subordinate movement, and shaping the crust extensively, creating various terrestrial features.

Fig. 4. Geographic treatment of the controlling sites around four selected continents and the resultant horizontal forces exerted on them. *F* (yellow arrow) denotes the horizontal force, while purple bar denotes the distance applied by the force. Dot with number denote controlling site. Note that the determination of ocean depth is artificially resolved from Google Earth software.

Table 1 Basic information for continents

Continent	Area (S)	Thickness (d)	Density (ρ)	Mass (M)	Site			Distance of site to site (L)		Tide range (Δh)	Ocean depth (h)
	km^2	km	kg/m^3	kg	Num.	Longitude	Latitude	km		m	m
					1	80^{o}W	2.0^{o}S	1_2	2,087	3	4,000
					2	70^{o}W	18.0^{o}S	2_3	1,153	3	4,000
					3	73^{o}W	28.0^{o}S	3_4	2,780	3	3,500
					4	73^{o}W	53.0^{o}S	5_6	2,308	4	4,500
					5	68^{o}W	52.5^{o}S	6_7	1,730	4	4,500
South American	17,840,000	6	3,100	3.21E+20	6	54^{o}W	34.5^{o}S	7_8	1,952	3	4,500
					7	42^{o}W	23.0^{o}S	8_9	2,525	3	3,000
					8	34^{o}W	7.0^{o}S	9_10	2,157	3	3,000
					9	53^{o}W	5.5^{o}N	10_11	836	3	2,000
					10	72^{o}W	12.0^{o}N	11_1	1,033	3	3,000
					11	78^{o}W	7.0^{o}N				
					12	6^{o}W	35.5^{o}N				
					13	17^{o}W	14.7^{o}N	12_13	2,535	2	4,000
					14	7^{o}W	4.6^{o}N	13_14	1,531	2	4,000
African	30,370,000	6	3,100	5.65E+20	15	8^{o}E	4.4^{o}N	14_15	1,696	2	4,000
					16	22.2^{o}E	34.7^{o}S	15_16	4,577	2	4,000
					17	30.4^{o}E	30.7^{o}S	16_17	886	2	4,000
					18	40^{o}E	16^{o}S	17_18	1,904	2	4,000
					19	51^{o}E	11^{o}N	18_19	3,237	2	4,000
Indian	4,400,000	6	3,100	8.18E+19	20	66.8^{o}E	25^{o}N				

					21	77.5^{o}E	8^{o}N	20_21	2,205	4	2,000
					22	80^{o}E	15.2^{o}N	21_22	846	4	2,000
					23	91.5^{o}E	22.7^{o}N	22_23	1,468	4	2,000
					24	94.3^{o}E	16^{o}N	23_24	801	4	2,000
					25	114^{o}E	23^{o}S	25_31	2,162	4	2,000
					26	117.2^{o}E	35^{o}S	25_26	1,370	4	3,000
					27	131^{o}E	31.5^{o}S	26_27	1,340	2	3,000
Australian	8,600,000	6	3,100	1.60E+20	28	149.8^{o}E	37.6^{o}S	27_28	1,846	2	4,000
					29	153^{o}E	25.4^{o}S	28_29	1,390	4	3,000
					30	142.4^{o}E	10.8^{o}S	29_30	1,970	4	1,000
					31	131^{o}E	12.2^{o}S	30_31	1,252	4	100

Note: all geographic sites refer to Figure 4 and their longitude and latitude are resolved from Google Earth software.

Table 2 Horizontal forces and resultant movements for continents

Continent	Horizontal force (F) N						Friction coefficient (ζ)	Resistance (f)	Combined force (F-f)	Acceleration (a)	Time for acceleration during a tide loading (Δt)	Displacement (D)
			Latitudinal East (+)	Longitudinal North(+)	Total	Inclination to latitude (°)		N	N	$m\cdot s^{-2}$	hour	mm/year
South American	F_1	2.46E+14	2.08E+14	1.30E+14								
	F_2	1.36E+14	1.30E+14	-3.90E+13								
	F_3	2.86E+14	2.86E+14									
	F_4	4.07E+14	-3.17E+14	2.56E+14								
	F_5	3.05E+14	-2.11E+14	2.20E+14								
	F_6	2.58E+14	-2.34E+14	1.10E+14								
	F_7	2.23E+14	-1.22E+14	-1.86E+14								
	F_8	1.90E+14	-6.31E+13	-1.80E+14								
	F_9	4.92E+13	3.25E+13	-3.70E+13								
	F_{10}	9.11E+13	8.83E+13	-2.26E+13								
			-2.03E+14	2.52E+14	3.23E+14	128.89	0.9965	3.22E+14	1.13E+12	3.41E-09	0.042	28.44
African	F_{11}	1.99E+14	1.76E+14	-9.22E+13								
	F_{12}	1.20E+14	8.49E+13	8.49E+13								
	F_{13}	1.33E+14	8.85E+12	1.33E+14								
	F_{14}	3.59E+14	3.38E+14	1.21E+14								
	F_{15}	6.95E+13	-3.05E+13	6.25E+13								

	F_{16}	1.49E+14	-1.25E+14	8.16E+13								
	F_{17}	2.54E+14	-2.35E+14	9.58E+13								
			2.17E+14	4.86E+14	5.33E+14	65.96	0.996	5.31E+14	2.13E+12	3.77E-09	0.048	41.11
Indian	F_{18}	1.73E+14	1.46E+14	9.22E+13								
	F_{19}	6.64E+13	-6.27E+13	2.18E+13								
	F_{20}	1.15E+14	-6.29E+13	9.65E+13								
	F_{21}	6.28E+13	5.80E+13	2.42E+13								
			7.88E+13	2.35E+14	2.48E+14	71.44	0.997	2.47E+14	7.43E+11	9.07E-09	0.036	55.63
Australian	F_{22}	1.61E+14	1.56E+14	4.15E+13								
	F_{23}	7.88E+13	-1.94E+13	7.64E+13								
	F_{24}	1.45E+14	4.47E+13	1.38E+14								
	F_{25}	1.64E+14	-1.58E+14	4.15E+13								
	F_{26}	7.74E+13	-6.26E+13	-4.55E+13								
	F_{27}	5.01E+12	6.10E+11	-4.97E+12								
	F_{28}	1.70E+14	9.10E+13	-1.43E+14								
			5.19E+13	1.03E+14	1.16E+14	63.39	0.995	1.15E+14	5.79E+11	3.62E-09	0.06	61.6

Note: all forces and distances refer to Figure 4.

A reconsideration of some terrestrial features

Continents, representing the upper part of the continental crusts, are being driven by the pressure yielded by tide loading to globally float. The pressure, which is always vertical to the continental slope, provides a non-horizontally push to squeeze the plastic oceanic crust in the front to form trench. The trenches around the margins of Eurasian and American continents are the examples. The moving continent, by means of basal friction, further pulls the crust beneath it and the adjoining oceanic crust, generating slight movement for them. The resultant periodically rupture and closeness of the oceanic crust, accompanied with the eruption of the magma from the deep of the earth and its subsequent nucleation, give birth to the mid-oceanic ridge. Figure 5 demonstrates how the mid-oceanic ridge forms under the effect of tide loading. The pressure at first pushes the continent to move. The moving continent, by means of basal friction, further drags the adjoining oceanic crust and yields strain for the latter. With the passage of time, the accumulated strain eventually fractures the oceanic crust in the middle to form a "V" shaped opening, allowing the magma to erupt dramatically. The rupture temporarily relieves the strain, the erupted magma subsequently cools by ocean to crystallize, forming new crusts. The newly formed crusts in turn weld/close the opening and terminate the eruption. As the pressure continues to push the continent to move, the strain again is yielded and accumulated, the following rupture and welding occur again. The newly formed crusts inevitably add height to the oceanic crust itself, this height accordingly falls with the increase of distance from the opening, because the newly formed crusts are being dragged slightly tilt to move away. If we treat this process over a long time, this results in the mid-oceanic ridge and the seafloor spreading (Hess, 1962; Vine and Matthews, 1963). The Mid-Atlantic Ridge could be the case. In addition to this, the moving continent provides not only drag to the oceanic crust in the rear and but also push (by basal friction) to the oceanic crust in the front, these drags or pushes or both of different directions to identical oceanic crust may deform the crust to fracture, allowing the magma to erupt and form the mid-oceanic ridge. The ridges around Pacific plate could be the case.

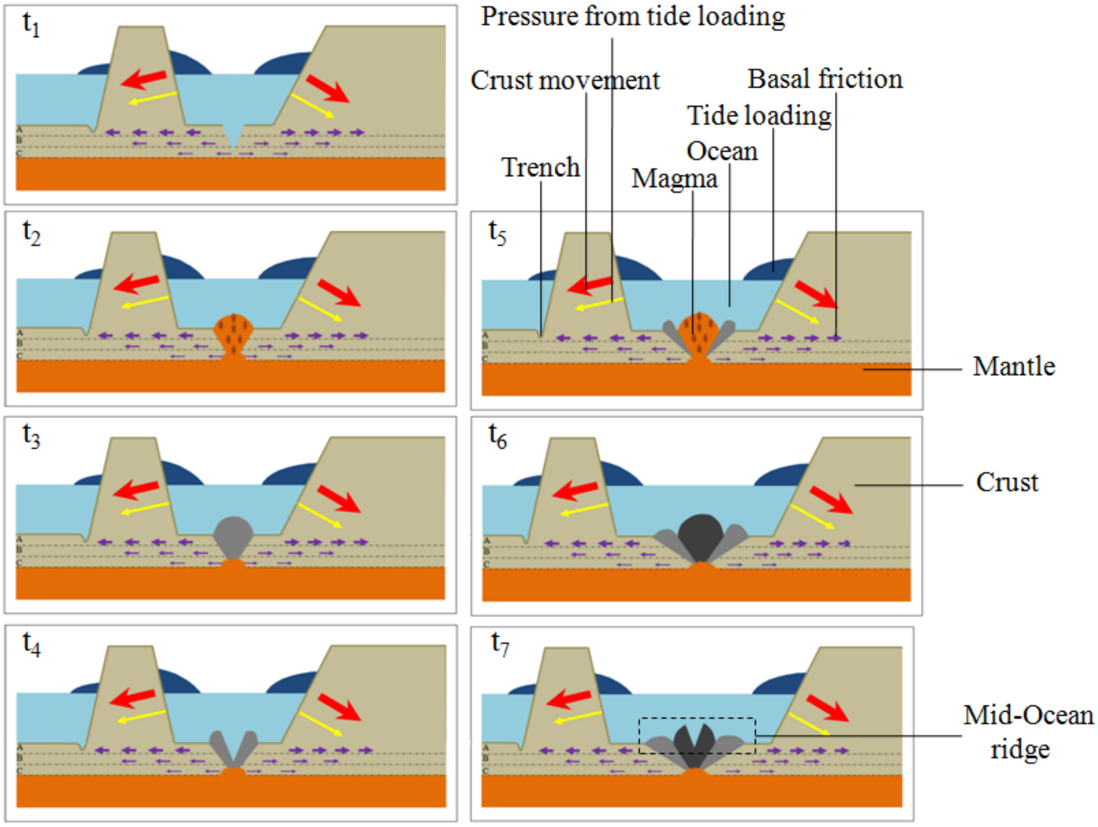

Fig. 5. Modelling the formation of seafloor spreading and mid-oceanic ridge. From t_1, t_2, …, to t_7, it shows a sequence of formation time. The lower lithosphere is divided into three layers A, B, and C, representing bearing the movements of different amplitude due to the drag exerted by the basal friction. Note that the pressure yielded by tide loading is always vertical to the slope, which tends to push the continent to move along a tilt path.

The loading of the continent onto the oceanic crust inevitably causes a geological instability that is likely related to local compression because of an addition of weight, forming activity of earthquake or volcano or both. This instability also may happen when two continents (Africa and Europe, for instance) collide. For the continent that is being surrounded by ocean, the pressure yielded by tide loading pushes its very side, this compresses the continent inwards, forming folded mountains and rifts. The collision of two continents also may create highly high mountains. As shown in Figure 6, the pressure yielded by tide loading is pushing Indian continent to impinge into Eurasian continent, because the push is not horizontal, this provides a bulldozer effect to uplift the materials in the front, eventually forming the Himalayas. It should be noted that, the Himalayas was long thought to be a result of the collision of Indian plate and Eurasian Plate. This understanding, in fact, is not exactly correct. Both Indian plate and Eurasian Plate have about the same rock density, a net result of the collision of these two would result in an addition of height. The thickness of the continental and oceanic crust is respectively 35 km and 6 km (Turcotte & Schubert 2002), the overlay of these two plates would yield a thickness of at least 80 km, even if both the folded situation of single plate and the early formed oceanic crusts between Indian Plate and Eurasian Plate aren't included. The presently height of the Himalayas (Mount Everest, 8,848m) is too low to match the required height. In contrast, if we treat the Himalayas as a result of the collision of two continents, it appears to be more rational. Both the Arabian Sea and Bay of Bengal, which surround Indian continent, have a depth of about 4,000 m, it is this sea depth to yield pressure to drive Indian continent to move. The height of Indian continent is generally no more 500 m, while Tibetan Plateau has a general height of about 4,000~5,000 m, if we add a continental curst of height 4,000 m, which is equal to the sea depth that provides the pressure, to Tibetan Plateau, the final height may be approximately reached. Similarly, the established understanding of the formation of the Alps, which believes these mountains to be formed as a result of the collision of African and Eurasian plates, is not too reliable. The Himalayas arc is almost vertical to the colliding belt. Different from this, the Alps arc is roughly parallel to the colliding belt, as shown in Figure 7(A). This suggests that the Alps could result from other collision. Here we ascribe Alps to a result of the collision of the moving Italian island and the remaining Europe region in the front (Figure 7(B)). As expressed in the formulas of the pressure, the pressure relates not only water depth but also height of tide. It is possible, the relatively deeper Ionian and Tyrrhenian seas contribute much pressure to the sides of Italian island, giving the island a dominantly push towards northwest, a combination of this push and another push yielded by tide loading at the Atlantic side gives birth to the Alps.

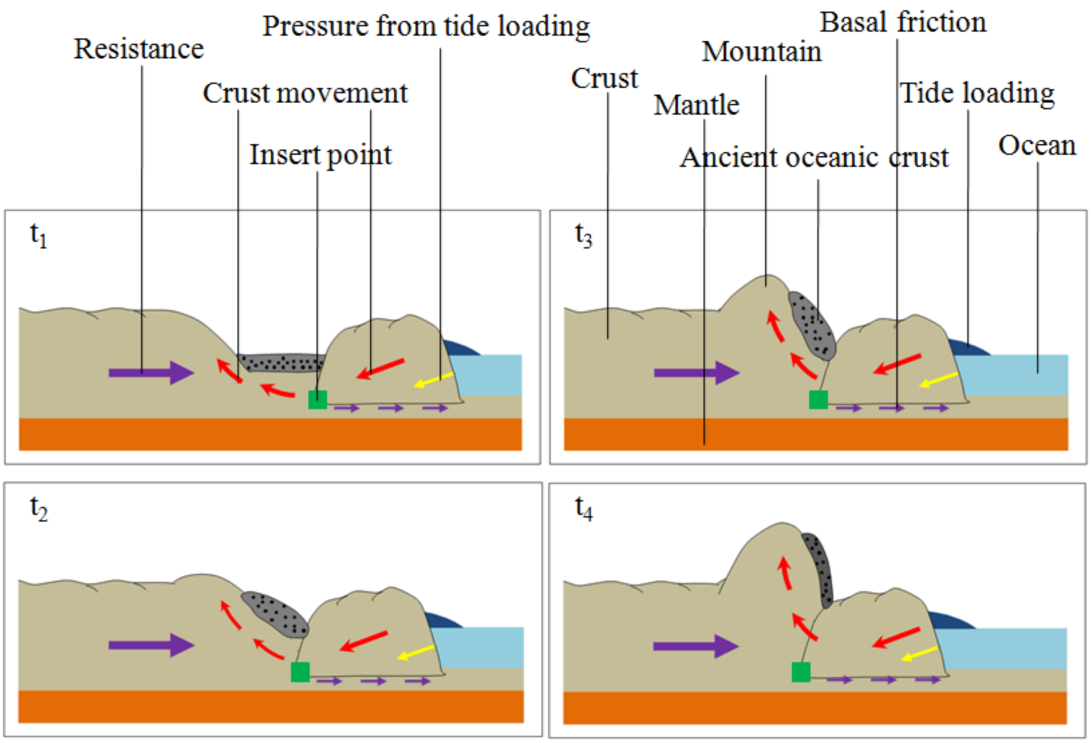

Fig. 6. Modelling the formation of the Himalayas under the collision of Indian continent and Eurasian continent. From t_1, t_2, …, to t_4, it shows a sequence of formation time.

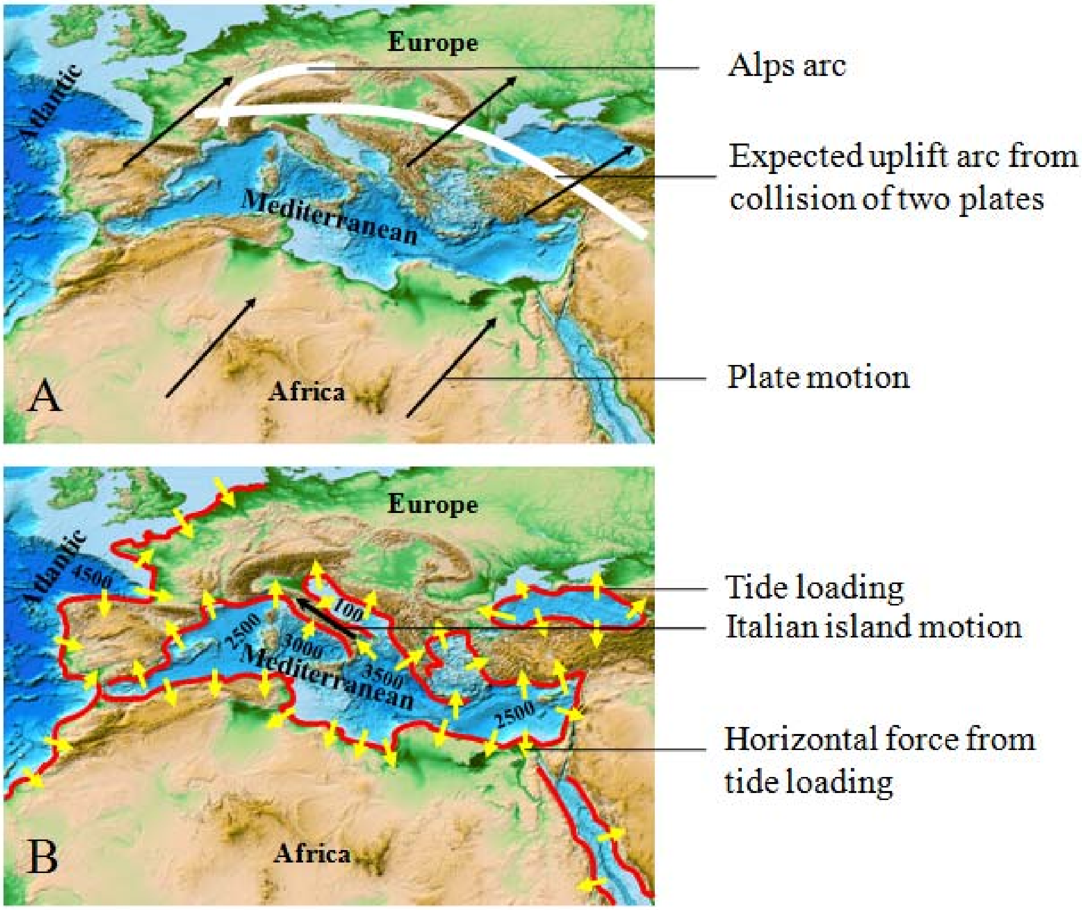

Fig. 7. Modelling the possible formation of the Alps. A compares the Alps arc expected from the collision of two plates to the real one. B shows the pressure yielded by tide loading around the Mediterranean and the Atlantic side. The ocean (sea) depth is roughly determined from Google earth software. The background map is produced from ETOPO1 Global Relief Model (Amante and Eakins, 2009).

Discussion

Tide loading is entirely global, this means that tide exists not only around continent but also over ocean. One of my works (unpublished) recently treats tide as a result of the oscillation of ocean basin that arises from the daily rotation of deformed solid earth in the curved orbits. According to that work, the Pacific basin is uplift (put down) two times per day, generating water movement back and forth. The presence of dynamic pressure thus becomes possible. The northwesterly movement of the Pacific Plate is most likely related to the static pressure yielded by tide loading onto the extensively-distributed islands in the northwest Pacific and to the dynamic pressure yielded by water movement over the ocean.

This work concludes plate motion mainly as a continental movement, namely, a movement of the upper part of the continental crust. Moreover, the moving continent by basal drag moderately entrains the crust beneath it and the adjoining oceanic crust. The proposed periodically rupture and closeness of the oceanic crust, reflecting alternate heat release from the earth's interior, may build up a connection to the past climate cycles supported by data from ice core and marine sediment (Petit, J. R. et al., 1999; Imbrie, J. et al., 1993; Bassinot, F. C. et al., 1994).

Various methods (marine geology, geophysics survey, and seafloor drilling, for instance) have confirmed the existence of many continental fragments and crustal remnants in the oceanic basins, generally, these fragments and remnants consist of either large ridges or plateaus (Ren et al., 2015). The most famous among them include Jan Mayen Ridge, Rockall Pleteau, Rio Grande Rise, Falkland Plateau, Seychelles Plateau, and so on. The formation of oceanic plateaus was thought to be a result of the combination of firstly rising of mantle plumes through the asthenosphere, subsequently flattening along the base of the lithosphere, and finally decompressed melting (Saunders et al., 1992). Once the origin of the mantle plumes, which is the mantle convection theory, is pendent, it is necessary to consider alternative for these fragments and remnants. This work really provides this solution. As we may infer from Figure 1, besides the pressure yielded by tide loading, the ocean itself also yields pressure, these two pressures together push the continent's slope to gradually sink. Once the continent submerged into the ocean during a long time scale, forming plateau is natural. Possibly, the ancient and isolated small-sized continents had fall into the oceans to create these ridges and plateaus we see today.

The pressure yielded by tide loading provides possibility to conceptually track the continental shift (Wegener, 1915 and 1924). Since tide loading is launched from east to west as the earth spins on its axis, the travelling water (if blocked) would accumulate to form larger tide. This allows the larger tides to load mainly at the east and west sides of the continents, while the weaker ones to occur mainly at the south and north sides. It's familiar that the largest tide occurs at the concave of some coast such as Bay of Fundy (tidal range here may reach up to 16 meters). The concave acts as a funnel to amplify tide. Figure 9 exhibits how tide loading serves the continental shift. At the time of Upper carboniferous the opening at the east of landmass firstly facilitates larger tide to load, the resultant pressure pushes the adjoining continents to move away. This in turns expands the opening further. The weaker pressure at the south of landmass gives little resistance to that expansion. With the passage of time, the landmass was slowly split and displays the shape at the time of Eocene. This, again, facilitates more ocean to enter, more tide to load, and also more pressure to be generated to push the continents. We believe, this feedback possibly runs across the first stage of the landmass's separation. The landmass was increasingly broken up until the advent of older quaternary, the primitive shapes of separated continents were formally established. After that time the tide loading continued to proceed, and the continents also continued to move away until present.

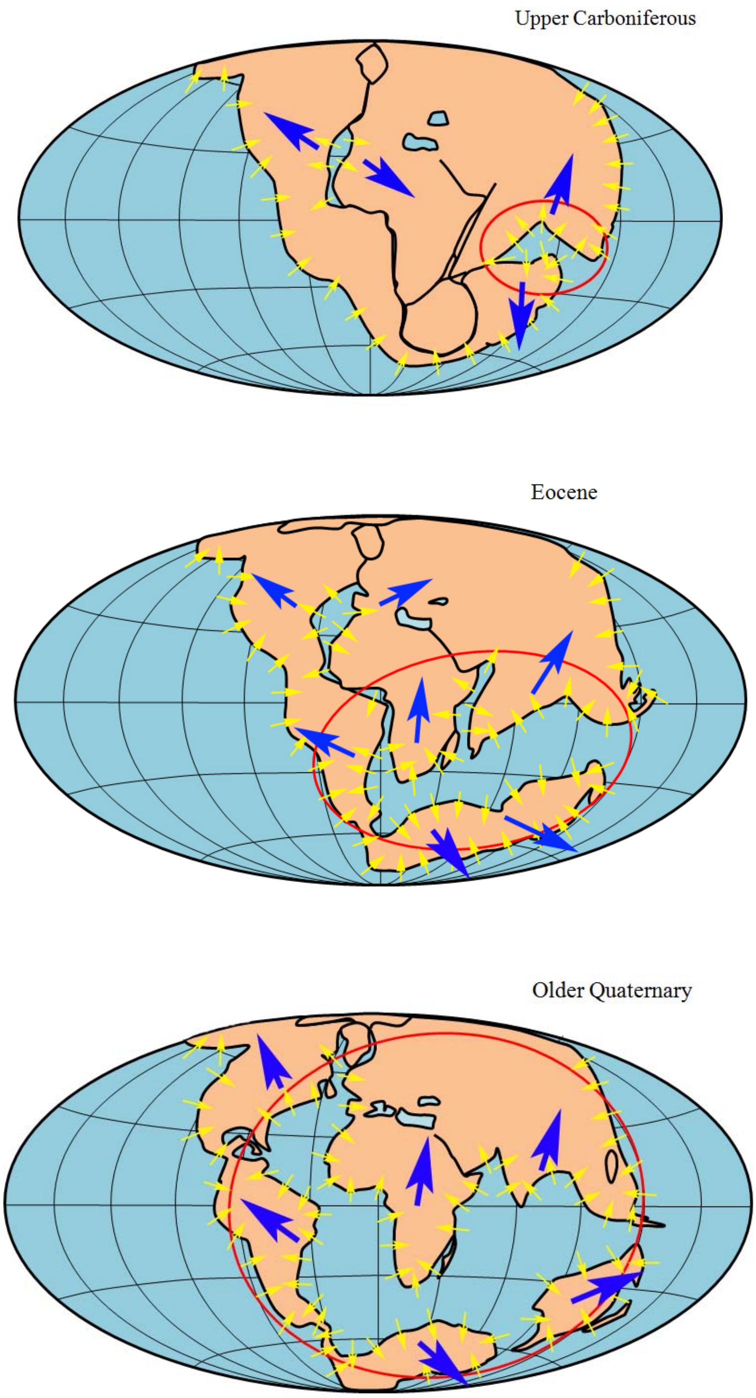

Fig. 8. Modeling the evolution of continental shift based on tide loading. Yellow and blue arrows denote respectively the horizontal forces yielded by tide loading and the resultant continental shift. Red circles represent an increasingly expansion of tide loading within the landmass. The background map is yielded referring to Wegener's work (1924).

One of the most unusual features around the mid-oceanic ridge is the transform faults cutting the ridge into a train of smaller sections. The understanding of transform fault is a preferred subject among scientific communities, but the origin of transform fault still remains in a state of debate (Gerya, 2012). A widely accepted view is the oceanic transform faults originated from plate fragmentation that is related to pre-existing structures (Wilson, 1965; Oldenburg and Brune, 1972; Cochran and Martinez, 1988; McClay and Khalil, 1998; Choi et at., 2008). Gerya (2010) recently theorized the transform fault of Mid-Atlantic Ridge and summarized (2012) that asymmetric crustal growth at mid-oceanic ridge can create some transform faults, while others can form earlier during the onset of oceanic spreading. Another matter of the transform fault we need to particularly note is very long and nearly-parallel structures across the ridge to exert the cutting, especially, these structures also appear within the Pacific plate where no ridge exists, as shown in Figure 8 (A). This implies that the ridge likely forms no earlier than these nearly-parallel structures. We thus consider a solution for the formation of the transform faults at the Mid-Atlantic Ridge. As exhibited in Figure 8(B, C, and D), the early Atlantic is relatively narrow, the pressure yielded by tide loading at first pushes the continents to move, the moving continents, by basal friction, further entrains the adjoining oceanic crusts, the accumulated strain finally fractures the crust into smaller nearly-parallel segments. The narrowness of the oceanic crust at this time facilitates longitudinal fracture to occur. With the passage of time, the oceanic crust widens gradually due to the opposed movements of the continents at the two sides, this fosters the latitudinal fracture to occur. For each of these segments, the leading drag to it is exerted from nearly opposed directions, the accumulated strain therefore rips each of these segments in the middle. Finally, as we demonstrated in Figure 5, a ridge is formed for each segment. Once we connect the ridges of all these segments together, they consist of the transform faults of the Mid-Atlantic Ridge.

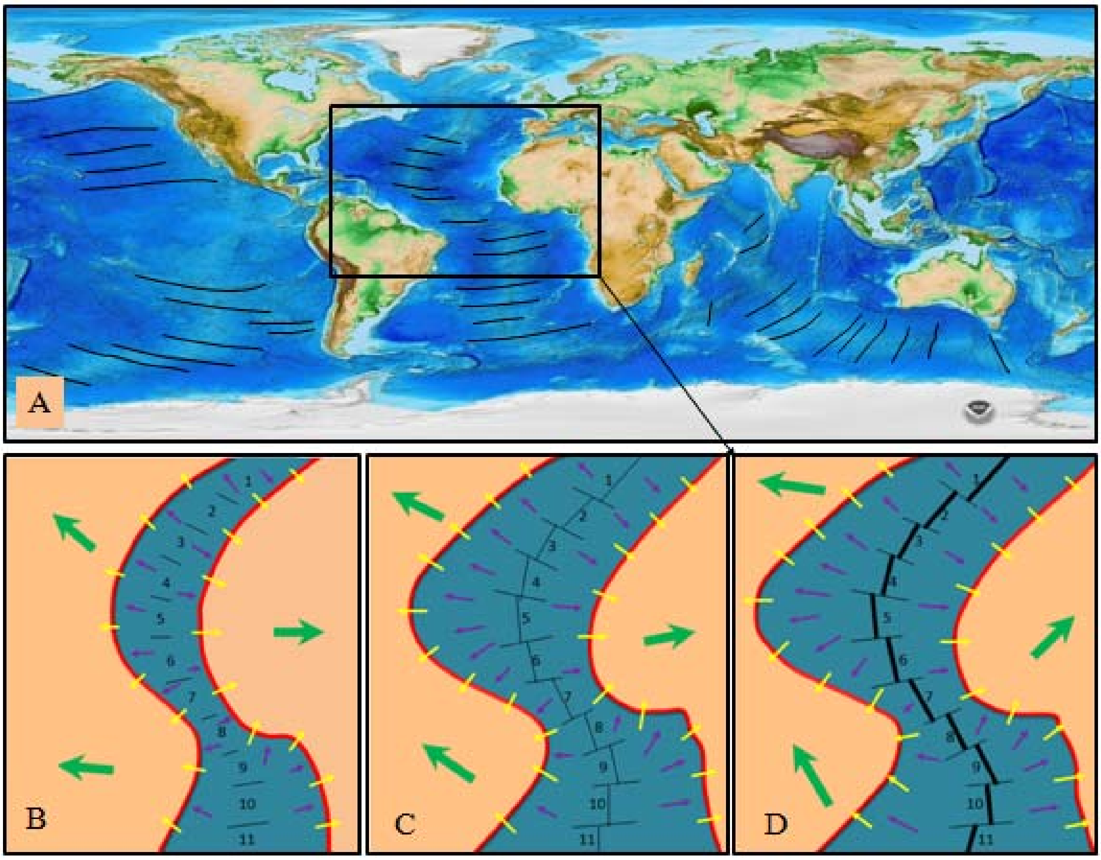

Fig. 9. Modelling the formation of mid-oceanic ridge and transform faults based on tide loading. A shows large, nearly-parallel structures (thin black lines) across over the oceanic crust.

The background map is produced from ETOPO1 Global Relief Model (Amante and Eakins, 2009); B, C, and D exhibit a sequence of how transform faults evolve together with the growth of mid-oceanic ridge. Yellow, green, and purple arrows denote respectively the pressure yielded by tide loading (marked with red around the margins of continents), the resultant movements of the continents, and the drag exerted by the moving continents to the oceanic crust. The thin black lines in B, C, and D represent nearly- parallel structures that match the ones in A. Number 1, 2, . . ., and 11 represent the fragments of the oceanic crust due to the fracturing, which consist of the section of transform faults.

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