Can a Horizontal Astronomical Driving Force and an Independent Vertical Convective Force Explain Global Tectonics?

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ABSTRACT

When Wegener first proposed that continents moved, he suggested that astronomical forces drove them. For this he was ridiculed. The force was much too small. In the last edition of his book, he allowed that convective force might be responsible. Despite the rejection and because of the failure to discover a convincing global convective driver, the idea of an astronomical driver has been revisited again and again, most recently by Carlo Doglioni and his colleagues in Italy. The idea of an extraterrestrial westward driving force is compelling in its ability to explain features. Like the idea of continental drift earlier, it will not easily go away.

This poster assumes that Doglioni's arguments effectively address objections regarding viscosity and conservation of angular momentum and that horizontal motions of plates are driven by astronomical interaction. To this I add the notion that subduction at continental margins is the result of independent convective force—an idea perhaps implicit in the notion of an astronomical driver. Consideration of independent horizontal and vertical forces presents a different perspective for global tectonic analysis. Here I look at geophysical constraints and analyze whether some tectonic features may be explained by independent forces. Among the questions considered and answered in the affirmative are these:

- Are rifts mere tears in the crust resulting from differential effect of the horizontal force?
- Can back arc basins can be explained by interaction between the forces where subduction blocks the horizontal motion of the lithosphere and the astronomical force causes a break to the west of the block?
- Once downward convection is triggered, can the astronomical driver push a continental mass over a subduction zone so as to create the subduction-related orogeny we see within continents?
- Does tensional astronomical force facilitate volcanism within arcs where vertical convective motion permits melting?
- Can interaction of convection and independent horizontal movement collapse continents and build mountains as in the Himalayas and Andes?

In the end, a chastened Wegener was certain of only one thing: "*The forces which displace continents are the same as those which produce great fold-mountain ranges*." Perhaps it takes *two* independent forces to build the great fold-mountain ranges.

Introduction

This poster is a personal project and is not part of any sponsored or institutional research. Its purpose is to present an hypothesis for a framework for analysis of global tectonics. The concept presented here is born of dissatisfaction with the currently predominant theory of edge driven plates. Crustal tensile strength seems inadequate to support such a system. And the linking of horizontal and vertical motion presents serious problems. At the same time, rejection of astronomical driving forces on the basis of assumptions about mantle viscosity seems unwise considering what we know and don't know about the deep Earth.

I don't pretend that the content here is all original, or perhaps original at all. The idea that I would emphasize—the perspective that I think leads to a solution—is an analysis which recognizes that the horizontal and vertical driving forces are independent. Once the independence is recognized, I think it is possible that each force, each motion, and each interaction of forces and motions can be analyzed to lead to a coherent scheme of global tectonics.

When Wegener first proposed his theory of continental motion, it was rejected, at least in part, for lack of an adequate driving force. His proposed astronomical driver was deemed to be too weak to overcome a measured viscosity that was based on the dubious and speculative assumption that viscosities are isotropic. Continental drift returned as a viable theory in the second half of the twentieth century when geologists envisioned a mantle-scale convective conveyor belt moving the continents. When the conveyor belt idea was falsified, parts of it were preserved in an attempt to preserve a theory of plate driving forces. So far as I can tell, no comprehensive reexamination has been undertaken.

As edge driven systems were analyzed, it became apparent that lower and lower mantle viscosities were required. The anisotropy of viscosity had to be recognized. In essence, the edge-driven theories have prepared the ground for a reexamination of the astronomical driver. That reexamination has never been pursued to an adequate end. Here I present some thoughts about how I think it could work.

The Horizontal Force

First, I consider the horizontal force independent of any constraints and interactions. The effect of the force is very complex and, I fear, not well understood. Nevertheless, numerous workers have made attempts to calculate it. There are three aspects to the horizontal force, all of which are interrelated and vortical in nature. Bostrom provided a simplified introduction to the East-West force with this diagram:

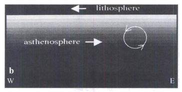
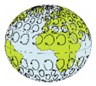
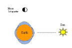


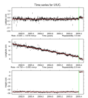
Fig. 3.11. (b) Vorticity induction and displacement direction of upper mantle relative to the lithosphere. Induction is effected in each volume element of an imperfectly elastic asthenosphere, acting so as to displace shallow and deep material simultaneously in opposite directions. In low latitudes, the axes of vorticity, normal to inscribed circle, are horizontal and aligned N-S into the paper. From Bostrom (2000) Fig. 3.11

Other aspects of the force that have been considered are the "pole-fleeing" force and Coriolis effect.



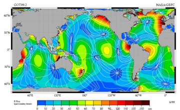
Past treatments of the force have used simple static force diagrams such as this one.





The reality of the situation is much more complex. GPS measurements suggest a complex periodicity and solution as a difficult problem in wave physics.

http://sideshow.jpl.nasa.gov/mbh/all/plots/UIUC.jpg



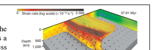
http://svs.gsfc.nasa.gov/stories/topex/images/TidalPatterns_hires.tif

This map of ocean tidal range is here to illustrate the complexity of the effect of an astronomical force on the face of a complex globe. While there may be an inclination to think of astronomical force as being directed from east to west—the static model that is often used in teaching about ocean tides—the dynamic expression will be more complex. Are closed basin waves relevant? What is the impact of tidal loading waves? And, of course, many other aspects which I haven't thought of.

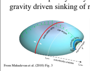
And finally, perhaps the most important consideration: ***an astronomical force acts on every bit of the earth***.

The Vertical Force

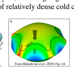
The vertical force would seem to require less explanation. All of the contemporary analysis, including edge driving theories, view it as a gravity driven sinking of relatively dense cold crustal material into a less dense warmer mantle.



From Schellart et al. (2007) Fig. 3



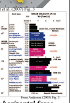
From Mahadevan et al. (2010) Fig. 3



From Mahadevan et al. (2010) Fig. 4A

Additional complexities introduced by the earth's spherical geometry explain the shape and dip of subducting plates.

An aspect of the vertical force that needs consideration is role of eclogitization. This is important to convection in two circumstances. First, it creates instabilities in very old oceanic crust. Second, it can take place where oceanic or continental crust is forced downward by overriding material creating an instability.



From Anderson (2005) Fig. 3

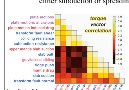
Bottom line: ***The vertical force is a gravity-driven convective force that is independent of the horizontal force.***

Evidence That the Forces Are Independent

If one assumes, as I have here, that the horizontal force is astronomical and the vertical force is convective, then they are by definition independent. Here I look for evidence that this assumption is correct.

There is no correspondence between subduction zones and spreading centers. Spreading centers are being subducted in places. In some cases, plate motion is parallel to subduction. In large areas, either subduction or spreading are not present.

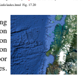
From Earth's Dynamic Systems, http://earthds.info/index.html Fig. 17.20



From Becker & Faccenna (2007) Fig. 5

Horizontal plate motions are negatively correlated with vertical forces

Horizontal spreading centers have no impact on subduction and subduction has little or no impact on horizontal ocean floor features.

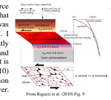


A Note on R.C. Bostrom's "Tectonic Consequences of the Earth's Rotation"

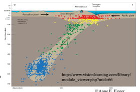
Bostrom's book covers much of the subject matter of this poster with more rigor than is presented here. Unfortunately, he does not draw his observations into any kind of comprehensive theory—or at least one that I can discern from his writing and presentation. Perhaps as a result, this potentially important book has apparently been largely ignored.

Global Constraints on Motions

The horizontal astronomical force is weak—weak enough so that many have presumed that it was insufficient to move plates. I assume here that it is sufficiently strong to overcome resistance and move the continents. To the right is a diagram from Riguzzi (2010) expressing a possible explanation for a low viscosity layer.



From Riguzzi et al. (2010) Fig. 9



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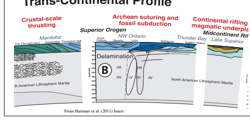
A discrete low viscosity layer at the base of the lithosphere suggests the opportunity for deep crustal structures to cross the layer and impact continental motion.

Many subduction zones extend down as far as the 660km discontinuity. These seem likely to act as anchors and block or impede horizontal movement.

Trans-Continental Profile



From Hammer et al. (2011) Insert

Continental keels—such as the 270km deep zone below the Superior Province—may impede movement or concentrate stress above a low viscosity zone.

ASTRONOMICAL FORCES DRIVE HORZONTAL MOTIONS

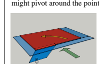
CONVECTION DRIVES VERTICAL MOTIONS

A different way to think about global tectonics

Interaction of the Forces

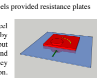
Any movement caused by the horizontal force would be opportunistic. Oceanic crust—and continents—would be expected to move in the direction of least resistance. A plate ending in a subduction zone would be one of those places—the horizontal force would essentially be pushing its load into a hole.

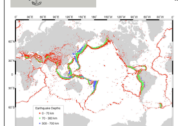
Where subduction zones acted as anchors to plates or deep continental keels provided resistance plates might pivot around the point of resistance.



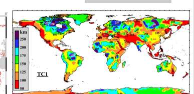
A slab anchor could act as a pivot.

A deep continental keel could pivot motion driven by the horizontal force, but because keels do not extend as deep as subduction, they may not block motion.





The blue deep earthquakes on this map may represent places where a low viscosity layer has been penetrated and motion is blocked or diverted.

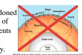


Cratonic keels in the blue areas may represent areas of resistance to plate motion. Not all of the shield areas present resistance as can be seen by the speed at which the Indian and Australian plates have moved.

Some Examples

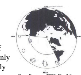
Rifts Are Tears

The 'conveyor belt' model spreading has been all but abandoned for lack of empirical support, yet it persists like some kind of zombie, displayed on scientific websites and taught to students as near fact. The notion that ridges result from deep seated mantle flow began as a corollary of the conveyor belt theory. Admittedly there is more evidence for active spreading than there is for the conveyor belt, nevertheless a reexamination seems in order. This poster won't resolve the debate between active and passive spreading, but a workable astronomical driver should help the debate.



Modified from http://pubs.usgs.gov/gip/dynamic/unanswered.html

When passive spreading is attributed to vague plate tectonic forces—forces most often attributed to edge forces that are poorly paired and applied thousands of kilometers away—it would seem more plausible to call on a force from below. If the force is, like the astronomical force, one that applies evenly across the globe, then a passive model becomes incrementally more plausible.



From Bostrom (2000) Fig. 3.8a

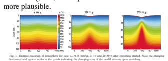
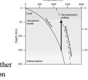
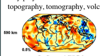


Fig. 3. Thermal evolution of lithosphere for case ... Note the changing horizontal and vertical scales in the panels indicating the changing sizes of the model domain upon stretching.

From Van Wijk & Cloetingh (2002)



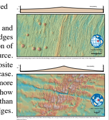
A passive rift opened by a horizontal force would create mantle upwelling resulting in decompression melting. Other factors such as expansive and exothermic serpentinization may play a roll. This is more consistent with observed topography, tomography, volcanism and heat flow.



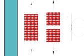
From Simmons et al. (2010) Fig.8a

Temperature above the 660km discontinuity does not reflect mantle-driven spreading.

Comparison of fast and slow spreading ridges gives little indication of a driving heat source. In fact the opposite seems to be the case. Faster, hotter more volcanic ridges show lower topography than slower ridges.



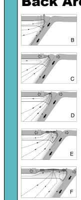
From Earth's Dynamic Systems, http://earthds.info/index.html Fig. 19.3



Tensile stress produces linear fractures normal to the force.

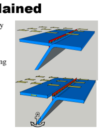
If rifts are tears, it has been noted that at least in part, the withdrawal of ductile mantle in stretching and an upwelling would help to explain excess down-drop in marginal basins. This idea needs to be explored in the context of an astronomical horizontal force.

Back Arc Basins Explained



This is a typical back arc model after Taylor and Martinez (2003) Fig. 16, which relies on a corner flow model.

Back arc basins are formed by rifting of arcs and continued spreading that is similar to mid-ocean spreading. While rifting may occur in east facing subduction zones, only those facing west host back arc basins. Back arc basins have greater asymmetry and more ridge jumps that oceanic ridges.



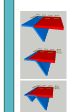
Because the horizontal force acts on the back arc in the same way as the oceanic crust east of the arc, there is a rifting force. If the slab descends to the point where it is anchored below a low viscosity layer, then there will be a rifting tendency at the weakest point—the volcanic arc. (The volcanism being facilitated by the rifting.) Rifting would progress in the same manner as mid-ocean rifting with upwelling and decompression melting. Asymmetry and ridge jumps are caused by the restricted opportunity for upwelling on the arc side of the rift.

Admittedly, this is highly simplified. Because of the interaction of forces within an arc and the effects of spherical geometry, the reality is much more complex. Some of the complexity is addressed in the adjacent box.

http://www.erictwelker.com/2011GSAPoster.pdf

Intra-Continental Orogeny Explained

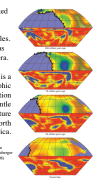
Orogeny far from continental margins has presented challenges for plate tectonic theory. While explanations have been offered, they have been difficult to reconcile with a uniform set of principles. An example of this is the "flat subduction" that has been used to explain the North American Cordillera.

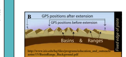


If the horizontal force is independent of the vertical force of subduction, then given the right circumstances, a plate can override a subduction zone. The overriding plate can go on to trigger subduction to the west of the first zone.

This is a tomographic reconstruction of past mantle structure under North America.

From Steinberger (2008)



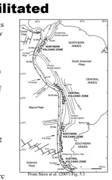


The anchoring effect of intracontinental subduction can result in extension west of the anchoring and explain the basin and range.

How one gets from overriding to orogenesis is a more difficult question. The weak horizontal force probably wouldn't be capable of building mountains absent circumstances such as those described in the adjacent box. The downward convection force isn't going in the right direction, but depressions caused by subduction could be filled with basinal sediments or thrust plates moved by the horizontal force or gravity and then isostatically rebound.

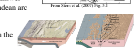
Arc Volcanism Facilitated

Volcanism in compressional environments is problematic from a theoretical point of view because of lack of opportunities for magma migration. In the simplified case of west dipping trenches examined in the adjacent back arc basin explanation, the introduction of tensional forces and opportunity for magma migration is obvious. In the case of east dipping subduction zones a theoretical introduction of tension is not as obvious.



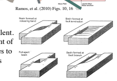
From Stern et al. (2007) Fig. 5.1

Here I look to Andean volcanism for an explanation. Volcanoes in the Andes are present in areas of a relatively steep dipping slab and absent in the areas of shallow "flat subducting" slabs, thus it seems, slab dip could be a clue. Unfortunately, the answer seems much more complex. The Andean arc was built in periods of alternating transpression and transtension. Contemporary volcanism is found in the transtensional parts of the arc.



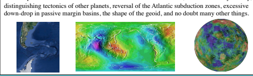
Ramos, et al. (2010) Figs. 10, 16

If the horizontal and vertical forces work independently, then opportunities for transtension would seem to be more prevalent. Because the horizontal force is independent of the of the vertical force they work at angles to each other and create a tension that creates transtension.



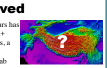
And More . . .

Analysis of global tectonics in terms of two independent forces has the potential to lead to simpler and more rational explanations of an number of subject areas that I don't have the time or space to address here. These include formation of oroclines, Pacific basin asymmetry, distinguishing tectonics of other planets, reversal of the Atlantic subduction zones, excessive down-drop in passive margin basins, the shape of the geoid, and no doubt many other things.

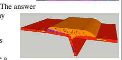


Continents Built, Conserved

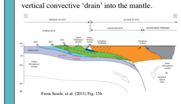
A question that has troubled geologists for a hundred years has been, how can the crust support the Himalayas for 20Ma+ without collapsing? In the context of plate driving forces, a more troubling question is, how can the Himalayas be supported if the force driving their uplift is downward slab pull of ductile crust directly under the mountains? The answer is that it can't. An independent horizontal force may solve the problem.



In cases where an "east" dipping subduction zone is overridden by a continent, continued "flat subduction"—the continental override—may create a steady state of sub-continental subduction and uplift. Recent papers have explained this with a "crustal channel flow and ductile extrusion" model where relatively rigid crustal material accumulates above a vertical convective 'drain' into the mantle.

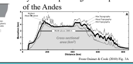


An independently driven convergent horizontal motion creates a dynamic situation that supports the uplifted mountains and plateau.



From Searle, et al. (2011) Fig. 15b

Convergence of continental and oceanic crust can lead to the same dynamic explaining the Altiplano of the Andes



From Ouimet & Cook (2010) Fig. 3A

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Conclusions

Understanding tectonic driving forces is key to solving tectonic problems, yet time and again, regional problems have been considered without regard to how they fit into an overarching theory. The origins of the forces that drive tectonics in each area aren't addressed or considered.

Here I have taken a mostly qualitative empirical approach to the problem. The horizontal astronomical force is known, despite the difficulty of describing it in detail. The downward vertical convective force is generally accepted. By definition, these forces have separate origins. And looking at the Earth, the observed horizontal and vertical motions support an independent origin.

Working from an assumption of independent forces, one can begin to come to rational solutions to some difficult problems of plate tectonics. If rifts are tears caused by the horizontal force, then the character of ocean ridges is better explained. Back-arc basins are a simple expression. Intracontinental orogeny can be explained where expressions of the vertical force—subduction zones—are overridden by astronomically-driven horizontal motions. Steady-state interaction between horizontal and vertical motions can explain construction and maintenance of the great mountain ranges.

Admittedly, this hypothesis contains speculation, but so too do the existing models. Despite an appearance of rigor, current models rest on assumed facts—lithospheric viscosity, tensile strength, and a host of others—that are little more than speculation. Given the uncertainty, we need to consider other models. The alternative framework presented here could better serve to enhance our understand of global tectonics.