Author comments to the response of Referee #2

I would like to thank this appointed Referee #2 for replying to author comments. The issues discussed previously and Referee reply will be itemized in the order in which the issues were presented in the reply. In each item, the issue previously discussed and Referee reply will be presented in italics and author comment follows in regular font.

I respectfully request this Journal to provide Referee # 2 reasonable time to reply to these comments if the Referee wishes.

1) I will respond briefly to a few of the author's responses to my review (referee #2). My comments are noted as "REPLY". Needless to say, the author's responses have not changed my opinion about the paper, but I appreciate the chance to respond to them directly.
AUTHOR: This Referee's general understanding of the work presented in the manuscript is, with all due respect, incorrect. Basaltic melting is not the driver of plate tectonics. The heat of mantle convection, Qh, available at the temperature of the hot reservoir temperature, Th, is the driver of the thermodynamic cycle. Some of this heat is lost as, Qc, to the surroundings at the cold temperature, Tc, and the difference, Qh-Qc, is the net thermal energy that can be converted to mechanical work, W. This work is delivered to the tectonic plates. This work, W, is also equal to the latent heat of melting of basaltic rock calculated at mantle's pressure. The heat of convection, as the source of energy that drives plate tectonics, is mentioned repeatedly and has a dedicated symbol, Qh, used in the thermodynamic equations throughout the manuscript. Please see Item 6 for more details.
REPLY: This thermodynamic analysis of thermal convection is incorrect. The energy that can be converted to mechanical work is equal to the energy released by potential energy (sinking slabs and rising plumes). The vast majority of this mechanical work is spent deforming the viscous mantle (viscous dissipation). A rather small amount is spent melting rocks, and this amount depends on the relative temperatures of the geotherm and the solidus of mantle rocks. The author is correct (sort of) that the difference in heat transport in hot reservoirs (upwelling plumes) and cold reservoirs (cold slabs) produces net energy – but this is due to the difference in adiabatic decompression and compression at different temperatures, and yields a net cooling. This cooling, however, is balanced by net heating by viscous dissipation. Therefore, the work done to drive plate tectonics (and all deformation in the mantle) is given by the rate of release of potential energy in the convecting system. This is a very different system than is described in this paper. Furthermore, there are many papers that have been written over the past few decades to describe this system. Here are some that come to mind: Conrad, C.P., and B.H. Hager (1999), Effects of plate bending and fault strength at subduction zones on plate dynamics, Journal of Geophysical Research, 104, 17551-17571. Backus,G. E. (1975), Gross thermodynamics of heat engines in deep interior of Earth, Proc. Natl. Acad. Sci. U.S.A., 72, 1555-1558.

Author comment

Convection of the upper mantle is not addressed in the literature. This convection is only 3.7% of the total mantle convection, please see lines 20 through line 29 of page 154. The fact that others approach plate tectonics differently is not a good reason to conclude that the work presented in the manuscript is incorrect. The same objectives can be achieved in different ways.

The availability of convertible energy to mechanical work is a necessary condition but insufficient. The means to convert the available energy to mechanical work is required. In principle, the tectonic engine is similar to steam and internal combustion engines. Energy is admitted into a chamber and a fraction of this energy is converted to mechanical work by the piston and piston rod. The midocean ridge encloses the tectonic engine chamber that is situated on a hot magma chamber. Part of the available magma latent heat of melting is converted to mechanical work by the tectonic plates that act as pistons and piston rods. This Referee has not provided the physical explanations and the means that convert the available energy into mechanical work.

The equations of thermodynamics used in the manuscript are proven equations and passed the test of time. They are used to calculate all engines known to us, and they must be adequate for the tectonic engine. Concluding otherwise would be unfair to the science.

2)AUTHOR: The word “viable” implies a hypothesis. The submitted work is not a hypothesis, it is based on proven and validated laws of thermodynamics, physics, and mathematics. The results of the calculations are in agreement with observations, experiments, and the work of others. The work is well beyond a hypothesis.
REPLY: The author does not test a hypothesis here – there is no prediction followed by a test against observations. I would argue that this work is more of an assertion, rather than a hypothesis.

Author comment

When there is a substantial agreement between mathematics and observations, the work is more than an assertion or a hypothesis, it qualifies to be valid, unless proven invalid based on mathematics and observations and not based on opinions.

3)AUTHOR: Any pressure build up cannot be accommodated by the viscous flow in the asthenosphere because the asthenosphere is incompressible. This is assumed as such in lines 12 and 13 of page 146. The work of Adams L. H. and Gibson R. E. (1926) suggests that earth’s rocks are practically incompressible. The reference follows: Adams L. H. and Gibson R. E.: THE COMPRESSIBILITIES OF DUNITE AND OF BASALT GLASS AND THEIR BEARING ON THE COMPOSITION OF THE EARTH, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES, VOLUME 12, NUMBER 5, P. 275- P. 283, May 15, 1926.
REPLY: Yes, that is true that we usually assume that viscous flow in the asthenosphere is incompressible. However, that does not mean that it does not flow in response to pressure gradients. Water is also incompressible, but it will move out of the way if you push on it. The asthenosphere DOES flow in response to pressure gradients – the resulting flow field is called Poiseuille flow.

Author comment

If the water has nowhere else to move out of the way, pressure develops. The asthenosphere cannot flow to accommodate pressure build-up because the surroundings are incompressible.

4)AUTHOR: At a pressure of 12,000 mega bars, the reduction in rock's volume, -V/V0, is 0.87%. In Table 1, page 278 of this paper, the experimentally measured and theoretically calculated reductions in the volume of rocks at different pressures are tabulated. Pressure values starts from 2000 mega bars and up, because at this and lower test pressures, the reduction in the volume of rocks is too small to be measured or calculated, and, therefore, are not shown in the table. Following basaltic rock partial melting at mantle's pressure, the increase in pressure is about 34.6 Kbars, line 7 and 8 of page 143. This is about 0.04 mega bars, which is too small to be tabulated in Table-1 of Adams L. H. (1926). Therefore, the reduction in volume of the mantle/asthenosphere is negligible and -V/V0=0. At the same time, the measured increase in the volume following basaltic rock melting is 14.4%, lines 18 through 22 of page 142, (Yoder 1976, p. 94). Or, +V/V0=0.14. This suggests that the reduction in the volume of the asthenosphere following basaltic rock melting is too small to accommodate the large increase in volume. Pressure builds up at midocean ridges as a result.
REPLY: Why are we using references from 1926 to quantify the material properties of rocks? There are many more recent papers with much more accurate constraints. Nevertheless, I don't have a problem with the incompressibility assumption. But pressure won't build up at a mid-ocean ridge due to melting for two reasons: First, the any pressure buildup will drive asthenospheric flow (Poiseuille flow) that will relieve some of this pressure. But more fundamentally: the melt is erupted on to the surface! So it is no longer around to build up pressure and drive the plate motions.

Author comment

Based on observations, enough melt is not erupted to the surface to relief pressure build up at midocean ridges. In order to relief pressure buildup at the ridges, at least 14% of the volume of the magma generated has to be erupted. The volume of the magma mass regenerated, M, Fig. 1 of page 160, is reasonably known. It is equal to the volume of new crust regenerated at midocean ridges. The volume can be calculated based on an average floor speeding rate of four centimeters annually, length of midocean ridges of approximately 60,000 km, and an average thickness of the new ocean crust regenerated at midocean ridges between 6.5 km and 15 km, Table 1, on page 157. The volume of the magma generated is approximately equal to 4 (cm/yr) x 60,000 (Km) x (6.5+15)/2 (km) x 10^{-5} (km/cm)=25.8 cubic kilometers annually. To relief the pressure at mid ocean ridges, a minimum of 0.14 x 25.8=3.6 cubic kilometers of magma must be erupted or released to the surface annually at midocean ridges. Using an average tephra bulk density of 1.65 and magma specific gravity of 2.94, the tephra equivalent volume is 7.2 cubic kilometers annually. The Volcanic Explosivity Index (VEI) corresponding to this tephra volume is 5.4, close enough to the size of Pinatubo colossal eruption. Such a colossal eruption, or equivalent eruptions, required annually at midocean ridges to relief the pressure build up at midocan ridges are not observed.

In a typical year, we observe about 55 volcanic eruptions mostly on land. They have VEI that ranges between 1 and 4, with and average of about 3. The total annual estimated tephra produced is approximately equal to 0.032 (cubic kilometers) x 55=1.74 cubic kilometers. This is approximately equal to 1 cubic kilometer of lava annually. The required magma release at midocean ridges to relief the pressure is 3.6 cubic kilometers annually, too large to be unnoticed, and it is not observed.

Therefore, based on observations, the volume of magma released at mid ocean ridges is too small to relief pressure build up at mid ocean ridges. The asthenosphere cannot flow to accommodate pressure build-up because the surroundings are incompressible.

5)AUTHOR: Midocean ridges are locations of tectonic plate spreading and separation. They are not locations of plate collisions. Yet, midocean ridges are the highest of the ocean floor. This can only be explained by pressure build up at midocean ridges. Other explanations fall short. Therefore, based on observations pressure build up at midocean ridges following magma generation is not presently being accommodated by the asthenosphere. Also, based on experiments, pressure build up at midocean ridges following magma generation cannot be accommodated by the asthenosphere.
REPLY: The elevation of the mid-ocean ridges is easily explained by thermal contraction of the seafloor as it moves away from the ridge. B. Parsons, J.G. Sclater, An analysis of the variation of the ocean floor bathymetry and heat flow with age, J. Geophys. Res. 82 (1977) 803–827. C.A. Stein, S. Stein, A model for the global variation in oceanic depth and heat flow with lithospheric age, Nature 359 (1992) 123–129.

Author comment

This thermal contraction of sea floor to explain the elevation of midocean ridges is physically unconvincing and falls well short in explaining this and other unanswered questions under Item 7 of author reply to the comments of Referee # 2.

6)AUTHOR: When basaltic rock melts, the total volume increases. If this increase in the volume cannot be accommodated by the surroundings, which is the case as discussed under Item 2 above, pressure develops. It is explained in details in Section 3, Thermodynamics, line 26 of page 140 through line 8 of page 143. Yoder 1976, conducted experiments and calculated the increase in the volume of basaltic melt to be about 0.049 cm3 per gram (Yoder, 1976, p. 94). This is approximately 14.4% increase in volume. Because the mantle is practically incompressible, large pressure develops at mid ocean ridges following mantle partial melting.
REPLY: Much of the melt is erupted to the surface, so it is removed from the system. This removed pressure buildup due to melting as a possible driver of plate motions.

Author comment

Enough melt eruption or release at midocean ridges to surface is not observed, and the melt is not removed from the system as explained under Item 4 of these comments. Consequently, large pressure builds up at midocean ridges.

7)AUTHOR: Mathematical or experimental research papers, by their nature, do not require large number of references. They are based on logic or results of experiments and there is no reason to provide references for matters that are obvious to the science. For instance, Adams L. H. (1926) cites seven publications. Should this Referee feel that references related to the work presented worth discussing, the Referee may suggest.
REPLY: It is true that large numbers of references are often not necessary, but it is not ok to omit citations to papers that are directly relevant, or that refute the ideas being presented. I've given the author a few classic papers that are relevant to this topic. There are many more in the literature.

Author comment

The work presented in the manuscript is authentic and it is not addressed in the leterature. The work is based on the work of others. Sec. 2, Model, assumptions, and data clearly references publications that have been influential in determining the nature of the work presented in the submitted manuscript. The tectonic and magma generation models are based on others' work that is referenced throughout the manuscript. The referenced literature by this Referee #2 does not calculate plate tectonics using the thermodynamic approach used in the manuscript; they use models that are not sensitive enough to variations of the temperature of ocean floor. While they are correct, they are inadequate for projecting the geological activities with climate change as stated in line 26 of page 138.

The references provided by this Referee # 2 do not refute the ideas being presented in the manuscript because this work is authentic and has not been published yet. The references have objectives and approaches that are different from the objectives or thermodynamic approach used in the manuscript. They are neither related nor relevant to the submitted work.

8)AUTHOR: The current science does not calculate plate tectonics using thermodynamics. The available tectonic models are not sensitive enough to variations in the temperature of ocean floor. While they are correct models, they are inadequate for projecting the geological activities with climate change as stated in line 26 of page 138.
REPLY: Actually, there are lots of paper that address the thermodynamics of plate tectonics and mantle convection. There are even some that address how plate tectonics would change in response to climate change. Here is one: Lenardic, A., A.M. Jellinek, and L.-N. Moresi "A climate change induced transition in the tectonic style of a terrestrial planet." Earth Planet. Sci. Lett., 271 (2008) : 34-42.

Author comment

The convection of the upper manrtle presented in the manuscript is authentic and unaddressed in the literature. It is based on the work of others. The manuscript clearly references publications that have been influential in determining the nature of the work presented in the submitted manuscript. The references provided by this Referee # 2 have objectives and approaches that are different from the objectives or thermodynamic approach used in the manuscript. They are neither related nor relevant to the submitted work.

9)AUTHOR: Magma generation and calculation of the degree of mantle partial melting is widely available in the literature, and there is no reason to calculate it in the manuscript. This will only add unnecessary pages and distraction off the subject matter. Yoder 1976 on page 107 suggests a degree of mantle partial melting of 30% based on rock phase diagrams, thermodynamics, mantle pressure, mantle temperature, and experiments. The calculated degree of partial melting using thermodynamics is in agreement. Please see line 21 through 24 of page 145. Based on lava samples, Yoder (1976, p. 112 and p. 113) concluded that the maximum degree of rock melting is in the order of 50% by volume, which is approximately equal to 45% by weight. The maximum calculated theoretical value based on Carnot cycle is 53%. Or, the maximum deviation from the observed is nearly 18%. Please note that the 53% is only a theoretical value that can never be achieved as stated in lines 24 of page 153 through line 2 of page 154. The actual maximum value of the degree of melting will be less than 53% but greater than 30%, in reasonable agreement with the observed of 45%. This is close enough and the thermodynamic argument is correct.

REPLY: You are not using any information about the solidus of mantle rocks in your calculations. Therefore, it is impossible to know how much melting will occur.

Author comment

I think that this Referee #2 believes that there is only one way to calculate the degree of mantle melting, and that is through rock phase diagrams only. This is not true with all due respect. The thermodynamic calculations are a reflection of the physics and chemistry of rock melting and what occurs deep in the mantle. Of course the degree of mantle melting can be calculated using thermodynamics; it is calculated in the manuscript as explained above in italics under this item. Both of the phase diagram and thermodynamic calculations have to cross-check each other. Otherwise, something would be wrong. The manuscript confirms that thermodynamics is in agreement with the physics and chemistry of mantle rock melting, a required agreement between calculation, experiment, and observations before the next step of the manuscript is pursued.

Information about the solidus of mantle rocks are widely discussed in the literature and the degree of mantle melting is available based on rock phase diagrams. Yoder 1976 dedicated a book on this subject and calculated the degree of melting based on the solidus of mantle rocks. Why should we re-invent the wheel? This will only add unnecessary pages to the manuscript and distraction off the subject matter.

10)AUTHOR: Mantle convection is not ignored; it is the heart and core of the subject matter. The heat of mantle convection is what drives the tectonic plates. The following are sample paragraphs extracted from the submitted manuscript:
REPLY: You are ignoring the work done to deform the mantle – this is an essential part of the energy balance of plate tectonics.

Author comment

Convection of the upper mantle is a closed loop and treated as a thermodynamic cycle as discussed under Sec. 2, lines 8 of page 137 through line 16 of page 138. Ocean crust and the rocky part of the upper mantle, which form the tectonic plates, move together in a closed loop. They are solid as they spread away from midocean ridges to a subduction zone. They are then digested in the mantle/asthenosphere, partially melted, and returned back to midocean ridges, together. There is no slip between ocean crust and upper mantle during this cycle, and therefore, the required work to deform the upper mantle is practically negligible. This upper mantle convection removes only 3.7% of the total internal heat produced in the earth's core, please see lines 20 through 29 of page 154.

The remaining 96.3% of the internal heat is removed by the greater mantle convection, which is discussed in the literature. While this convection is important, it is irrelevant to the discussion presented in the manuscript, which addresses only the convection of the upper mantle. Certainly, work is required to deform the mantle. This work, however, is not a manuscript objective. Accordingly, the thermodynamic system is carefully selected to include all of the mantle and the earth's core. Please see lines 25 to 27 of page 145. With this system selection, the work required to deform the mantle and its subsequent dissipation as heat are made internal processes to the system as defined. They are irrelevant to the surrounding tectonic plates as selected.

For the sake of the discussion, if the thermodynamic system is redefined as the envelop enclosing ocean and land crusts, the mechanical work of plate tectonics and its subsequent dissipation as heat become internal processes to this system as selected. Except for occasional tsunamis, this system exchanged only heat with its surrounding ocean and atmosphere, because the mechanical work of plate tectonics and its equal heat dissipated cancel out within the selected thermodynamic system.

11)AUTHOR: I respectfully have to disagree and this comment should be given no consideration. First, the work presented in the manuscript agrees closely with observations, experiments, and the work of others. The agreement is substantial and robust. Second, this Referee has not dedicated sufficient time to read the manuscript as it is evident from this reviewer's comment under Item 6. Third, unfortunately the existing tectonic models do not use thermodynamics; they are not sensitive enough to the temperature of ocean floor and cannot be used to project the geological activities with climate change, a major objective of the manuscript. And fourth, there are ongoing controversies with the current tectonic science and unanswered questions.
REPLY: I think my comments above show that I do not agree with these statements. Note that the author has not demonstrated that the work presented here "agrees closely with observations, experiments, and the work of others". In my view, this paper is far from being publishable in a major scientific journal.

Author comment

I respectfully disagree.

12)AUTHOR: For instance, there is no universal agreement among scientists as to the nature of energy or force that drives plate tectonics. Some tectonic plates do not have slabs, yet they move. What drives these slab-less plates? Basic mechanics suggests that under the pull of slabs, midocean ridges must level off with time, but they do not. Midocean ridges are rising instead. What maintains the observed lithosphere uplifting at midocean ridges? Midocean ridges are locations of tectonic plate spreading and separation. They are not locations of plate collisions. Yet, midocean ridges are the highest of the ocean floor. What maintains the observed lithosphere uplifting at midocean ridges? Why ridge push exists in the first place? Is ridge push a cause or an effect? Plate tectonic motion is a closed loop. The available positive potential energy of gravity is equal to the negative potential energy of gravity required for the motion. They are exactly equal and cancel out. What is the nature of external force that causes the observed tectonic motion? And finally, the existing tectonic models fail to explain the observed increase in geological activities with climate change, not to mention calculating them.
REPLY: Some of these points are well-explained by our current understanding of plate tectonics (such as the elevation of the mid-ocean ridges) and some are still under debate (forces that drive plate tectonics). There is little discussion of what is known and not known about the mantle – the paper starts at a very different point of understanding compared to our current knowledge. For example, the basic explanation for the elevation of the mid-ocean ridges is not the subject of debate and there are many papers showing that it is explained by cooling of the oceanic lithosphere – yet none of this work is cited in the paper.

Author comment

As mentioned previously under Item 7 of author reply to the comments of Referee # 2, there are ongoing controversies with the current tectonic science and unanswered questions. The basic explanation for the elevation of the midocean ridges based on cooling of the oceanic lithosphere is, in my opinion, unconvincing and still a subject of debate.

The submitted manuscript addresses convection of the upper mantle, which is a small fraction of the total mantle convection, only 3.7% of the total. This upper mantle convection is not addressed in the literature, and to the best of my knowledge, there are no relevant or related publications to cite in the manuscript. Those referenced by the Referees are unrelated or irrelevant to the work presented in the manuscript. The submitted work does not start at a different point of understanding of the current knowledge; it is based on the current knowledge and contributes to our understanding of plate tectonics.

13)AUTHOR: All what it takes is just one unexplained observation to render a theory obsolete, or at least be skeptical. The current tectonic science has many unanswered questions and many observations to explain. The submitted manuscript, on the other hand, answers all of these questions and calculates the observations as well.
REPLY: Obviously I disagree with the last sentence here.

Author comment

I respectfully disagree and the numbers speak for themselves.