

Overall review:

I think this is an important contribution to the study of plate tectonics and it should be published with some substantive revisions. There are specific content questions below in the "Content notes" section, as well as extensive technical (usage/grammar/spelling) notes in the "Technical notes" section.

What is the rationale for splitting the Pacific absolute plate motion into three segments instead of two? The Hawaiian-Emperor bend is an obvious reason for the 46 Ma split, but the reason for the 20 Ma split is not explained. Some general results are shown for the "2046" model but no conclusions are made and detailed results are not shown. Perhaps removing these results would improve the paper, keeping it focused on what the author is more sure of.

More detailed explanation of the quaternion filtering is needed, perhaps an example of a few iterations. The source code should be published as part of the supplemental material.

Please add the 0 Ma values to the plots in Figures 5 and 6, and double-check the colors used with the caption. I see only one gray color, which I take to be for South America based on the values plotted, as well as a tan color which is not described in the caption, but appears to be for Africa.

Ben Horner-Johnson
ben@rice.edu

=====

Content notes

Abstract:

Why is the 90 degree difference in absolute plate motion directions for the Australian and Pacific plates such strong evidence against thermally driven "roller" convection? Explain.

The motion of Australia towards the north (roughly) and the Pacific towards the west (roughly) fits with their motions away from the spreading ridges on the southern (Australia) and eastern (Pacific) edges.

1 Introduction:

Page 24:

Is the history of the Hess preprint necessary? Especially if the information was later published in Hess 1962?

Page 25, lines 6-12:

Norton superimposed transposed past locations of what on Asia, Africa, etc.? Are these supposed to be past locations of one of the listed plates relative to the Indo-Atlantic hotspots that are now transposed to Hawaii?

Page 26, lines 6-8:

This appears to assume whole mantle convection and strong subducted material impinging on the CMB. Is there any seismic evidence for this?

Page 27, line 9:

There is no reference for Sandwell and Smith, 1992. Doesn't this refer to the Sandwell and Smith, 1997 JGR article and map?

2 Improved resolution of absolute pacific plate motions:

Page 28, lines 18-21:

Why cite an unpublished manuscript for a quotation that could just as easily be written into the paper?

3 Filtering euler poles:

Page 29, lines 5-6:

Include the relevant figures (perhaps updated or cleaned up from the poster). Searching the entire poster for one out of twenty-seven figures took time (plus downloading a 25 MB file). The abstract text in the poster is cut off and many figures have color bars attached but don't require them. Adding the relevant figure to this manuscript shouldn't be that difficult. Improving it (color vectors by age?, using updated 1024 filter iterations) would make it more useful.

Page 29, lines 7-10:

Reword this awkward sentence (deep positive mass anomalies provide mass anomalies...). Here's a suggested reworking:

"My interpretation then, and now, is that phase changes in subducted lithosphere, such as pyroxene to spinel, provide the deep positive mass anomalies observed in the degree 4-10 packet of geoid anomalies, and that the sinking of these positive mass anomalies provides the driving force for plate tectonics (Bowin 2000)."

Page 29-30: quaternion filter routine

Is there a publication specific to the routine? Is there any way to estimate how many iterations produce an optimal result (error reduction for each iteration, stop when reduction is below a chosen threshold)? How smooth is smooth enough? or too smooth? More details and a simplified example would be useful for understanding the process.

A possibly useful reference for addressing uncertainties of plate reconstructions with respect to the hotspots is

Andrews, D. L. Gordon, R. G., and Horner-Johnson, B. C., 2006. Uncertainties in plate reconstructions relative to the hotspots; Pacific-hotspot rotations and uncertainties for the past 68 million years. *Geophys. J. Int.*, 166, 939-951, doi:10.1111/j.1365-246X.2006.03029.x.

Page 30, lines 4-6:

Is the 46 Ma point included in both the 68-46 and 46-0 segments for the 4448 model? The 2046 model does not include the 46-44 and 22-20 stage poles as written. Should the 2046 model be described as 68-46, 46-20, and 20-0 Ma?

Page 30, lines 11,13:

Why change from 1000 to 1024 iterations? Do the results change from the 2005 poster (1000 iterations) when recalculated with 1024 iterations? Is there a statistical improvement? Would fewer iterations produce the same result (statistically)?

Page 31, line 4:

Are these smoothed Euler and stage poles available anywhere?

Page 31, line 11:

Based on Figure 2, there may be a bend in the Cocos plate stage poles at 46 Ma, but the projection may be disguising it. Have you tried using a different projection or transforming the coordinates to be plotted closer to the equator on a Mercator map?

Page 31, lines 15-18:

This is another instance where some statistical understanding of how much smoothing is significant would be useful. Knowing how many iterations should be used for smaller sequences of stage poles would prevent the loss of information from oversmoothing. Could a plot be

produced showing the before and after positions of the poles? If not for all plates, then at least for Pacific, Nazca, and Cocos?

4 Plate tectonics and conservation of angular momentum:

Page 33, line 3:

Of course plates accelerate and decelerate ... how else would there be changes in spreading rates? Cande & Kent, 1992 and Heustis & Acton 1997 both discussed plate velocity changes.

Page 34, lines 1-10:

Is the angular momentum for a 1x1 degree square being determined from the mass of one square cm of lithosphere 40 km thick? There are a lot of square centimeters in one square degree.

If the lithosphere is 150 km thick, wouldn't the mass be much higher due to the other 110 km of thickness?

What are the scaling factors assuming 100 km thick lithosphere, which is closer to the commonly used thickness?

Page 34, lines 20-22:

These lines are discussing the results rather than describing the method used to produce the results.

Pages 34-35, lines 26-27 and 1-4:

Why do Figures 5 and 6 stop at 62 Ma instead of going out to 68 Ma? Why don't they show the 0 Ma values for angular momentum, mass, area?

It appears from Figure 5 that Pacific angular momentum had been on the rise from a low at 62 Ma towards the present.

I estimate the total angular momentum from Figure 5 at 2 Ma and 62 Ma as $1.38E27$ and $1.56E27$, respectively. Pacific plate angular momentum at 2 Ma and 62 Ma comprise 50% and 24.4% respectively, of the total.

African plate angular momentum decreased until 60 Ma, then increased until 46 Ma, and then slowly decreased until 2 Ma (if the gray triangles refer to Africa). This corresponds to 6.5 and 4.2% of total angular momentum.

If the tan triangles are Africa, then I'm reading the African angular momentum as 12.8% at 62 Ma and 1.3% at 2 Ma. Is there an increase in African angular momentum between 2 Ma and 0 Ma?

Estimates from Figure 5:

	Af(gray)	Af(tan)	Pa(red)	Total	%Af(g)	%Af(t)	%Pa
2 Ma:	9.0×10^{25}	1.9×10^{25}	6.9×10^{26}	1.38×10^{27}	6.5	1.4	50.0
62 Ma:	6.5×10^{25}	2.0×10^{26}	3.8×10^{26}	1.56×10^{27}	4.2	12.8	24.4

Page 35, lines 5-9:

Why list these values of plate area for 0 Ma when they are in Table 2? Or are these values for a different age?

5 Global plate velocity map images:

Page 36, lines 25-28:

Are there references to be cited about the end of spreading in the Tasman Sea? I seem to recall seeing titles for some recent papers about this. "grown that way" could be better explained.

Page 37, lines 6-7:

Describe the second thrust fault. The text refers to two, one being a "southern one dipping northward". Is the other the subduction zone?

Page 37, lines 11-15:

What caused the opening of the Atlantic ocean? Where are the subduction zones pulling North and South America away from Africa and Eurasia if slab pull is the sole driving force of plate tectonics? I don't see how all other driving forces have been shown to be eliminated based on the geometry of two absolute plate motions. Perhaps a diagram explaining how this eliminates all other forces?

6 Results and conclusions:

Page 38, lines 23-25:

Remove conclusion 5 - this isn't a result or conclusion.

Page 40, lines 13-15:

Any relation to the deceleration of India ~55 Ma (page 24, line 12)?
Are there other plate velocity changes related to that time period?

References, page 44:

Sandwell & Smith, 1997 is missing.

As GMT was used to produce the plots, adding a reference to Wessel & Smith, 1991 would be a way to acknowledge their contribution.

Wessel, P. and W. H. F. Smith, Free software helps map and display data, EOS Trans. AGU, 72, 441, 1991

Table 1, page 45:

Are the age ranges " >83 my" supposed to be "0-83 Ma"?

Table 2, page 46:

Why does South America have a smaller angular momentum ($0.88053E+26$) than Nazca ($0.91796E+26$) yet have a larger percentage (6.7983% vs. 6.57989%) of total angular momentum? When I use the total angular momentum ($1.3951E+27$) and to calculate South America's percentage of the total angular momentum, I get 6.31159%. This explains the 100.46% for the sum of the total angular momentum percentages. Correcting the 0.49% excess percentage for South America in the table brings the total % angular momentum to 99.98%.

Adding up all of the angular momenta from Table 2, I get $1.39483E+27$ for the total instead of $1.3951E+27$. Using the former total to calculate percentages of the total, this sums to 100.00%.

Are the area and angular momentum percentages known to 6 significant figures? For Nazca, is the difference between 3.20241% and 3.202% that vital? Include the total area in the header for "% Total area". Perhaps using 10^6 km² for area and 10^{25} kgm²s⁻¹ for angular momentum units and reformatting the columns would be clearer.

Figures 1-3, pages 47-49:

Could the Euler poles for 68, 46, 20, and 0 Ma be signified in some way (labels in black text, filled circles)? That would help with understanding how well the quaternion filtering is working on the stage poles.

Figure 5, page 51:

What are the open circles in the plots? They appear to be totals.
What are the black spots in the later images? They are described as contours about errant velocity values in the text (why are the values "errant"? How do they occur?).

Are the changes in area too small to appear on the log scale?

I don't see two kinds of gray triangles (Africa, South America).

Comparing the 0 Ma triangles in the upper left graph in this figure with the values for angular momentum in Table 2 shows some discrepancies. Actually, the 0 Ma triangles aren't shown, these are the 2 Ma triangles, the 0 Ma values really should be shown. The caption colors are not matched in all cases. I have sorted Table 2 by decreasing % total angular momentum and extracted the total angular momenta below.

Table 2:	Figure 5:	color	Matches_Table2?
pa 0.68590E+27	0.675E+27	red	Yes
au 0.26953E+27	0.275E+27	light blue	Yes
sa 0.88053E+26	0.775E+26	gray	No (value)
nz 0.91796E+26	0.298E+26	light purple	No (value)
na 0.65326E+26	0.950E+26	orange	No (value)
an 0.64633E+26	0.650E+26	dark purple	Yes
af 0.58020E+26	0.195E+26	tan	No (value/color)
in 0.41384E+26	0.450E+26	pale yellow	Close
co 0.10320E+26	0.138E+26	green	Close
eu 0.78757E+25	0.775E+26	yellow	No (value)
ar 0.72817E+25	0.725E+25	lighter blue	Yes
ca 0.47057E+25	0.475E+25	blue-green	Yes

Please see my attached figure (BowinFig5_6.jpg) for more details.

Figure 6, page 52:

What are the open circles in the plots? They appear to be totals.
What are the black spots in the later images? They are described as contours about errant velocity values in the text (why are the values "errant"? How do they occur?).

Are the changes in area too small to appear on the log scale?

What causes the drop in mass and area at 12 Ma for Antarctica? It's such an outlier and it causes a noticeable drop in total angular momentum.

Figure 7, page 53:

Explain the black dots in the older parts of the figures.
The resolution should be much higher for each of the parts of the figure so that zooming in to see detail is better supported than in the current manuscript (this may be an effect of the PDF creation process).

Supplement S1:

What plate is represented by "po" in the table? There's a section of "an-po" stage poles.

=====

Technical notes (things to correct)

1. Use actual superscripted exponents instead of "E+27" to refer to 10 raised to the 27th power (commonly written as 10²⁷ in plain-text).
2. When reporting on angular momentum, a half-space between kg and m would be useful for clarity (at first I thought it was improper SI usage for kg).

Abstract

Line 13: (note 1)

1 Introduction:

- Page 24, line 11: "ocean drilling sites" should be "Ocean Drilling Program Sites" according to ODP publication guidelines.
- Page 24, line 12: "at about 55 Myr" should be "at approx 55 Ma" where approx is the symbol `\approx` in LaTeX (two wavy lines).
- Page 24, line 13: un-capitalize "Plate Tectonics".
- Page 24, line 21: strike comma after "investigators".
- Page 24, line 22: "assent" should be "ascent".
- Page 24, line 24: un-capitalize "Plate".
- Page 24, line 27: add "hotspot" before "track".
- Page 25, line 2: "develop" should be "developed".
- Page 25, line 4: "conclude" should be "concluded".
- Page 25, line 6: shouldn't "plates" be after South America?
- Page 25, line 11: "47 Million years" should be "47 Ma".
- Page 25, line 21: "Km" should be "km".
- Page 25, line 25: "11- infinity" should have an m-dash and no space between 11 and infinity.
- Page 26, line 9: strike the comma after anomaly in "anomaly, that"

2 Improved resolution of absolute pacific plate motions:

- Page 27, line 4: "pacific" should be "Pacific"
- Page 27, line 6: "distribute" should be "distributed".
- Page 27, line 6: the closing parenthesis should be after "intervals" instead of after "4 Myr".
- Page 27, line 9: double check 1992 as reference year (not 1997?); add citation to reference list.
- Page 27, line 10: replace "Using" with "They used".
- Page 27, line 11: strike the commas in ", which past points,".
- Page 27, line 13: "such" should be "each".
- Page 27, line 16: strike the apostrophe in "normal's".
- Page 28, line 3: "each plumes" should be "each plume's".
- Page 28, line 13: un-capitalize "Plate".
- Page 28, line 15: strike the apostrophe in "spacing's".
- Page 28, line 15: "Euler Poles" should be "Euler poles".

3 Filtering of euler poles:

- Page 28, line 23: capitalize "euler".
- Page 28, line 24: un-capitalize "Plate".
- Page 29, line 1: un-capitalize "Plate".
- Page 29, line 2: "Myr" should be "Ma".
- Page 29, line 3: un-capitalize "Plate".
- Page 29, line 8: "provides" should be "provide". [see content note]
- Page 29, line 11: "Myr" should be "Ma" in both places.
- Page 29, line 13: "Myr" should be "Ma".

Page 29, line 18: un-capitalize "Plate".
Page 29, line 27: "plate's" should be "plates"
Or: rewrite as "of Euler poles for the Pacific and other plates".

Page 30, line 3: "Myr" should be "Ma" in both places.
Page 30, line 4: "Myr" should be "Ma" in both places.
Page 30, line 5: "Myr" should be "Ma".
Page 30, line 7: strike comma after "1,".
Page 30, line 6: "Myr" should be "Ma" in all places; note "M yr" after "46".
Page 30, line 9: "the original's midpoint" might be better stated as "the original series' midpoint" or "the midpoint of the original series"
Page 30, line 11: insert "and" before "used 1000".
Page 30, line 15: "Myr" should be "Ma".
Page 30, line 16: "Myr" should be "Ma".
Page 30, line 17: "Myr" should be "Ma".
Page 30, line 23: un-capitalize "Plate".

Page 31, line 1: un-capitalize "Northern Hemisphere".
Page 31, lines 3-4: un-capitalize "Southern Hemisphere".
Page 31, line 7: "plate No. 11, Fig. 2" should be "Fig 2, plate 11"
Page 31, line 8: strike "striking".
Page 31, line 11: strike comma after "is that".
Page 31, line 12: "Myr" should be "Ma".
Page 31, line 16: "Myr" should be "Ma".
Page 31, line 21: "Myr" should be "Ma".
Page 31, line 22: "Myr" should be "Ma".
Page 31, line 26: un-capitalize "Plate" in both places.
Page 31, line 27: "Myr" should be "Ma".

Page 32, line 2: "Fig." should be "Figure".
Page 32, line 11: strike apostrophe in "acceleration's".
Page 32, line 13: strike quotations marks around "no-net-torque".
Page 32, line 15: un-capitalize "impulse".
Page 32, line 19: strike "or planetismal" or correct the spelling of "planetismal" to "planetesimal".

4 Plate tectonics and conservation of angular momentum:

Page 32, line 22: change "Earths" to "Earth's".
Page 32, line 23: add hyphens to "no net torque".

Page 33, line 2: "Fig." should be "Figure".
Page 33, line 12: "259" should be "359".
Page 33, line 14: "Myr" should be "Ma".
Page 33, line 16: "Myr" should be "Ma".
Page 33, line 27: "Kgm" should be "kg" if referring to mass.
Page 33, line 27: change "40 km thick column, 1 cm² of lithosphere" to "40 km thick, 1 cm² column of lithosphere,".

Page 34, line 1: "plates's" should be "plate's".
Page 34, line 12: "Fig." should be "Figure".
Page 34, line 13: "(kgm)" should be "(kg)" if referring to mass.
Page 34, line 17: "Myr" should be "Ma".
Page 34, line 19: "Fig." should be "Figure".
Page 34, line 23: "shows" should be "show"; "Myr" should be "Ma".
Page 34, line 24: replace "presently" with "and".
Page 34, line 27: "Myr" should be "Ma".

Page 35, line 2: "Myr" should be "Ma".
Page 35, line 5: If axis label is fixed in Fig. 5, "Myr" should be "Ma".

5 Global plate velocity map images:

Page 35, line 21: should "48--62" be "62--48"?; "Myr" should be "Ma".
Page 35, line 22: un-capitalize "Total Angular Momentum".
Page 35, line 23: "Myr" should be "Ma".
Page 35, line 25: "Myr" should be "Ma".
Page 35, line 27: "Myr" should be "Ma".

Page 36, line 2: "Myr" should be "Ma".
Page 36, line 4: "Myr" should be "Ma".
Page 36, line 10: strike "quality of the".
Page 36, line 10: "composted" should be "composited".
Page 36, line 15: "Myr" should be "Ma".
Page 36, line 20: "Myr" should be "Ma".
Page 36, line 22: "Myr" should be "Ma".
Page 36, line 25: "pacific" should be "Pacific".

Page 37, line 15: "Myr" should be "Ma"; un-capitalize "Plate".
Page 37, line 17: "Hot Spot" should be written "Hotspot" without the quotes.

6 Results and conclusions:

Page 37, line 24: add a comma after "Further".

Page 38, line 2: un-capitalize "Plate Tectonics".
Page 38, line 6: "Myr" should be "Ma".
Page 38, line 10: un-capitalize "Plate".
Page 38, line 15: "pacific" should be "Pacific".
Page 38, line 22: "Myr" should be "Ma".
Page 38, line 24: "Myr" should be "Ma".

Page 39, line 8: un-capitalize "Plate"; "Myr" should be "Ma".
Page 39, line 11: un-capitalize "Plate".
Page 39, line 13: "Myr" should be "Ma"; un-capitalize "Plate".
Page 39, line 14: un-capitalize "Plate".
Page 39, line 15: "Myr" should be "Ma".
Page 39, line 16: "Myr" should be "Ma".
Page 39, line 21: un-capitalize "Angular Momentum".
Page 39, line 27: "Neoprotersrozoic" should be "Neoproterozoic".

Page 40, line 3: "planetismal" should be "planetesimal".
Page 40, line 4: un-capitalize "Plate Tectonic".
Page 40, line 6: remove quotes around "no-net-torque".
Page 40, line 8: un-capitalize "Impulse".
Page 40, line 13: "Myr" should be "Ma".

Acknowledgements:

References:

Table 1:

Table 2:

Page 46, header line 2: "Myr" should be "Ma".

Figure 1:

Figure 2:

Figure 3:

Figure 4:

Page 50, caption line 2: "Myr" should be "Ma".

Figure 5:

Page 51, caption line 2: "Myr" should be "Ma". Also in the x-axes of the figures.

Figure 6:

Page 52, caption line 2: "Myr" should be "Ma". Also in the x-axes of the figures.

Figure 7:

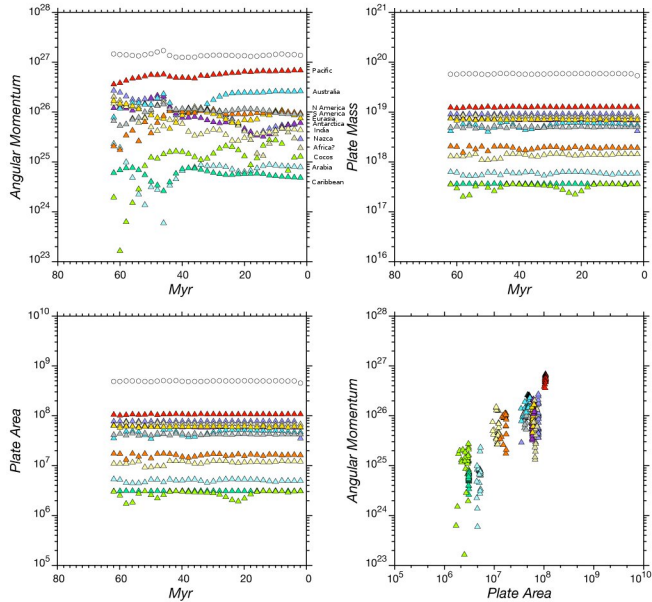
Page 53, caption line 1: un-capitalize "Million"; "Myr" should be "Ma".

Page 53, caption line 2: "Myr" should be "Ma".

Page 53, caption line 3: "mm/a" should be "mm/yr" to be consistent with the rest of the text.

Angular Momentum - 4448

Figure 5



Angular Momentum - 2046

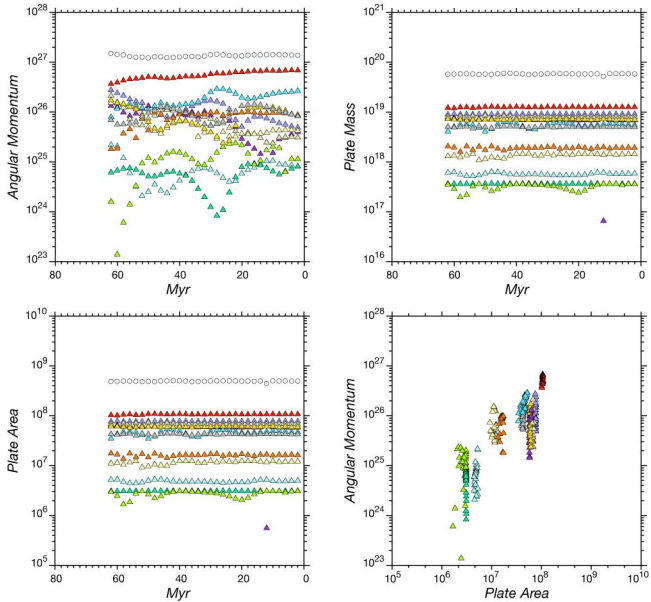


Fig. 5. Angular momentum, plate mass, plate area and angular momentum vs. plate area for the 4448 filtered data for 62-0 Myr. Color ID for plates: af (dark grey), an (dark purple), ar (light blue), au (dark blue), ca (dark blue green), co (green), eu (yellow), in (pale yellow), na (orange), nz (light purple), pa (red), and sa (light gray).

Fig. 6. Angular momentum, plate mass, plate area and angular momentum vs. plate area for the 2046 filtered data for 62-0 Myr. Color ID for plates: af (dark grey), an (dark purple), ar (light blue), au (dark blue), ca (dark blue green), co (green), eu (yellow), in (pale yellow), na (orange), nz (light purple), pa (red), and sa (light gray).