Lunar Tidal Signature Found in Records of Earth's Relative Paleointensity*

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ABSTRACT

A search of composite stacks of relative paleointensity SINT2000 and PISO-1500 for coherence with a simulated lunar tidal strain over the past 1 Myr shows significant coherence at periods near 10,000 and 8000 years respectively. The relative paleointensity stacks contain paleointensity records from a worldwide distribution of oceanic sediments from up to 34 individual cores. Tidal strains were estimated from a non-dissipative simulation of lunar range. Our search for coherence between lunar strain and relative paleointensity is based on a representation of long term fluctuations in geomagnetic intensity as a sequence of growths and decays, which are due to a tidally-induced parametric instability in Earth's fluid core. An important consequence of this depiction is the precise temporal location of 6 reversal events over the past 2 Myr. A parametric instability in Earth's core is consistent with both the success in predicting reversals and the coherence between relative paleointensity and lunar tidal strain. Indeed the periods found for coherence are geophysically plausible for the growth of parametric instability in Earth's core. Accordingly we conclude that these results are consistent with a parametric instability participating in the geodynamo.

1 Composite Paleointensity Stacks

Global properties of paleomagnetic fields are enhanced by stacking records from widely separated drill cores. The 34 cores of the SINT2000 stack vary significantly in overlapping coverage over the 2 myr period. The PISO-1500 stack was achieved through simultaneous stacking both by amplitude and time. Both stacks are plotted in Figure 1.

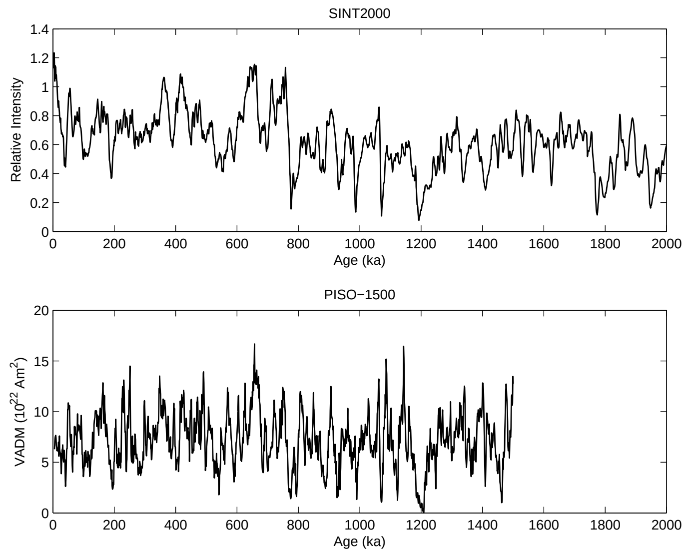

Figure 1. Composite paleointensity stacks, SINT2000 (upper) and PISO-1500 (lower) expressed as Virtual Axial Dipole Moment.

2 Model for Geodynamo Controlled by Parametric Instability

- **Elliptical straining by lunar tide of circular streamlines couples with a pair of rotational core modes to produce elliptical parametric instability**
- Helicity of rotational modes produces an α-dynamo [Olson (1988)]
- Paleointensity is a proxy for fluid velocity [Moffatt (1978)]
- Growths and decays seen in figure 1 are assumed to be exponential, corresponding to growths and decays of parametric instabilities
- Lunar tidal strains, corresponding to millennial geomagnetic time scales, have existed throughout the planet's history.
- **Coherency between lunar tidal strain and paleointensity provides evidence that elliptical parametric instability has existed in Earth's core due to lunar tidal strain**

3 Extraction of Lunar Tidal Strain Rate from Paleointensity Stack

Paleointensity shown in Figure 1 is modelled as a transient, with stages of growth, decay and otherwise stable intervals. We have developed an algorithm which recovers these rates. Paleointensity is filtered and an optimal tolerance for significant growth and decay is selected for the entire record. Figure 2 shows the rates recovered from the SINT2000 record of Figure 1 for a filter length of 7 Kyr and a tolerance of 0.4 of the standard deviation in amplitude.

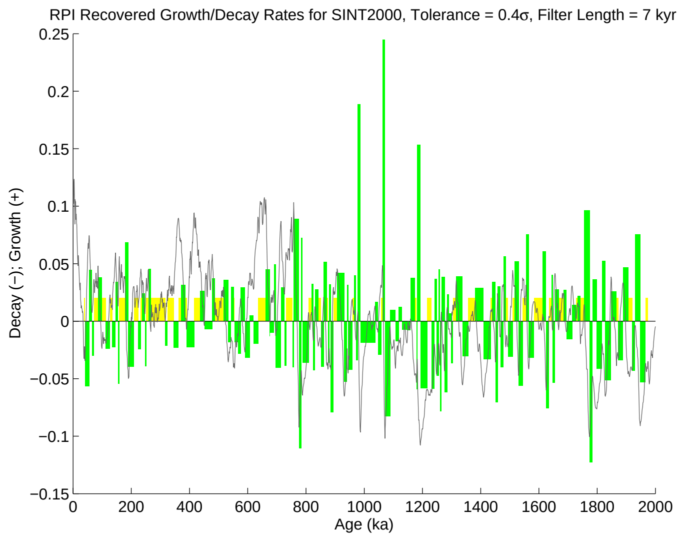

Figure 2.SINT2000 data (grey) and recovered growth and decay rates (green) and stable states (yellow).

Our RPI model says the the growth rate is $(\epsilon\Omega - \sqrt{E}\Omega)$ while the decay rate is $-\sqrt{E}\Omega$. Hence the difference between growth and decay rates is just $\epsilon\Omega$ which we call the raw rate and identified here with the **lunar tidal strain rate**. Here ϵ is the external strain, E is the core Ekman number and Ω is Earth's rotation rate.

Adjacent growth and decay rates of Figure 2 are subtracted, but as their signs are opposite this becomes a summing operation. The summed results yield the raw growth rates which are plotted in Figure 3.

Also plotted in Figure 3 are the locations of all the reversals that are known in the past 2 Myr. These reversals coincide with the largest raw growth rates found using our algorithm and expected growth and decay properties of a parametric instability in Earth's fluid core.

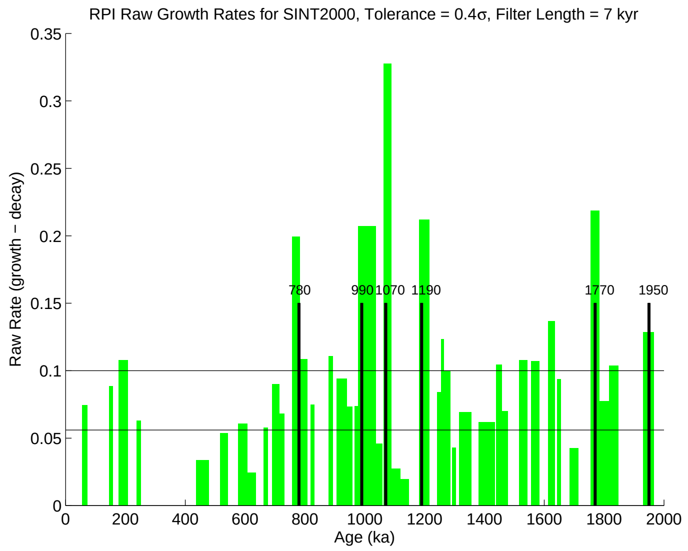

Figure 3. Raw rates from SINT2000 data and locations of paleomagnetic transitions from Cande and Kent, J. Geophys. Res., Vol. 100, No. B4, pp. 6093 – 6095 (except 1190). Horizontal lines are present tidal (upper) and precessional (lower) strain rates.

4 Simulated Lunar Range over 1 Myr

Figures 2 and 3 imply that an external strain has been recovered from the paleointensity data of Figure 1. Accordingly, we carried out a simulation of the Lunar orbit in order to estimate the lunar tidal strain during the time interval of the paleointensity record of Figure 1. Shown in Figure 4 is the Lunar range found from a simulation of the lunar orbit over the past 1 Myr.

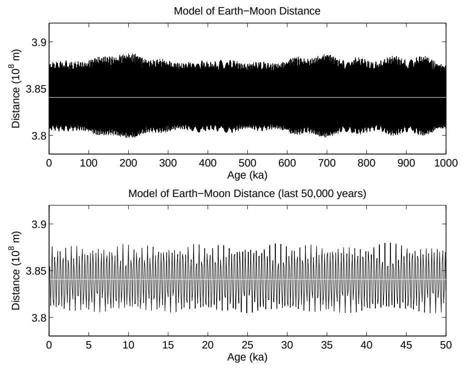

Figure 4. Simulated Earth-Moon distance over the past 1 Myr from non-dissipative orbital calculation by S. Mikkola (upper). Expanded scale of simulation over the first 50,000 years (lower).

5 Coherence between Composite Paleointensity and Lunar Range over 1 Myr

Since the Lunar tidal strain depends on the inverse cube of the Lunar range, we looked for coherence between paleointensity and Lunar Range^{-3} over a common 1 Myr interval with both the composite stacks of paleointensity shown in Figure 1. Use of multiple tapers in the coherency calculation led to a 95% confidence level at a coherency of 0.162. Since the sampling intervals for the simulation were at 100 years while the paleointensity stack was sampled at 1000 years, interpolation and filtering of the paleointensity data was necessary.

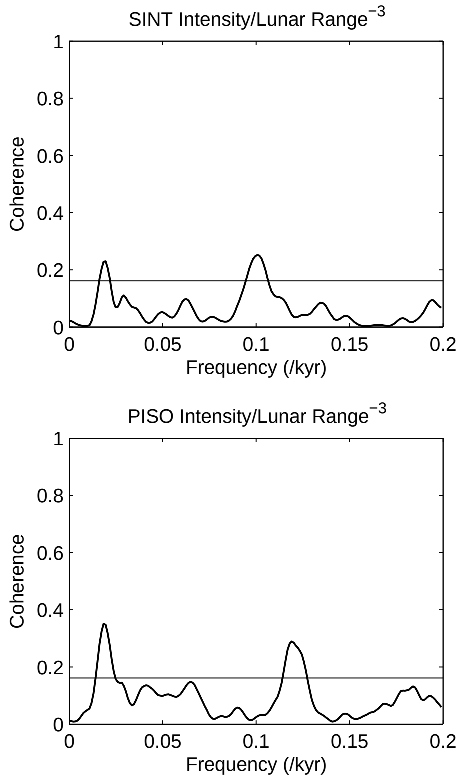

Figure 5. Coherence between lunar tidal strain over the past 1 Myr and composite paleointensity of SINT2000 (upper) and PISO-1500 (lower). Horizontal bar shows significance at 95% confidence level. Periods of significant coherence were found near 10,000 years for the SINT2000 stack and 8000 years for the PISO-1500 stack.

6 Update: Coherence between Composite Paleointensity and Lunar Range over 2 Myr

New simulations carried out over 2 Myr were sampled at the same interval as the paleointensity data of Figure 1. Thus no interpolation or filtering was needed for the coherency calculation. The interval shown is longer because without the smoothing, results for frequency greater than 0.2 are reliable. The number of tapers depends on the chosen effective frequency resolution and number of samples in time series. Number of tapers is lowered because of fewer time samples and therefore the confidence level increases.

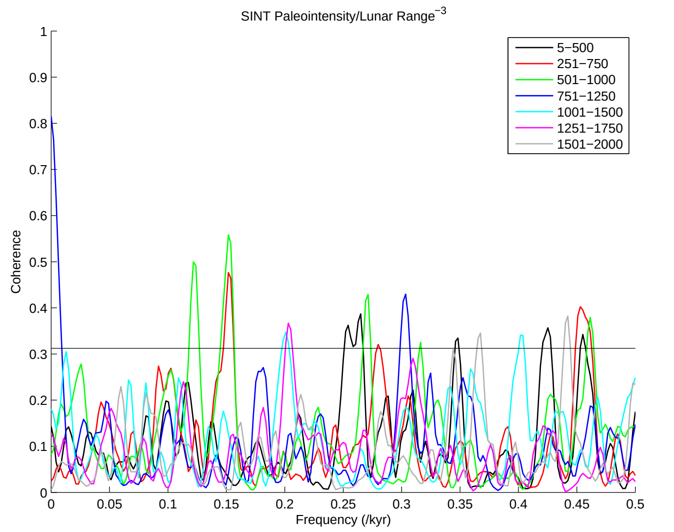

Figure 6. Coherence between composite paleointensity stack SINT2000 and lunar strain from simulation over the past 2 myr, in 7 overlapping 500 myr intervals. The horizontal line shows the threshold for significance at 95% level.

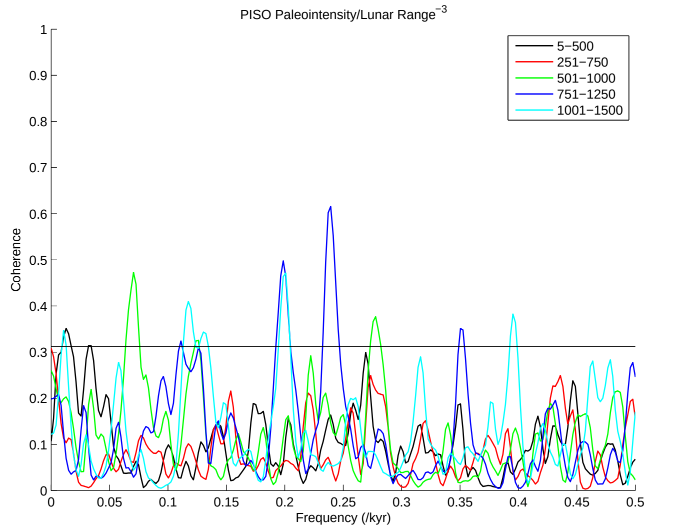

Figure 7. Coherence between composite paleointensity stack PISO1500 and lunar strain from simulation over the past 1.5 myr, in 5 overlapping 500 myr intervals. The horizontal line shows the threshold for significance at 95% level.

7 Summary

- Search for Lunar tide as source of recovered strain rates from Paleointensity stacks reveals signifcant coherency between lunar stain and paleointensity
- Agreement between the peak strain rates obtained from the SINT2000 data and known polarity events is consistent with a significant role of rotating parametric instability in the geodynamo
- Polarity reversals match the peak raw strain rates obtained from the SINT2000 data using our algorithm. Actual strain rates of Earth compare favourably with raw rates found from the SINT2000 data