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Supporting Online Material for

Intermittent Plate Tectonics?

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Supporting Online Material

Geochemical proxies for subduction flux

We make use of proxies for slab flux based on the magmatic effect of subduction. In particular, we consider geochemical measures of melt removal, which are assumed to be dominated by the extraction arc-related melts. Use of the Nb/Th ratio (*S1*) is based on the observation that during melting at subduction zones, Ni partitions less readily into the melt than Th, so that, as more melt is extracted from the mantle, the Nb/Th ratio of the mantle will increase over time (*S1*). A mantle evolution history was created on this basis, using samples in which this ratio could be accurately measured and that could be dated (*S1*). These data, augmented by other observations, were then fit to a polynomial (see Figure 2 of *S1*). To estimate the mantle depletion rate, which should correspond to subduction flux, we have taken the derivative of this polynomial fit (blue curve in Figure 2). The red curve in Figure 2 represents a histogram of the $^4He/^3He$ ratio in ocean island basalts (OIB) (*S2*). The latest data on the partition coefficient for He, suggests that it is significantly larger than previously thought, and larger than either U or Th. As such, the $^4He/^3He$ ratio should reflect the depletion state of the mantle. Peaks in a histogram of $^4He/^3He$ can thus be interpreted as periods of time of strong depletion. In the case of He, however, there is no explicit age attached to these values of the ratio. Parman (*S2*) assigned an age by assuming that the peaks in $^4He/^3He$ correspond to peaks in crustal growth rate inferred from the age distribution of zircons. While Parman (*S2*) shows data both from MORB and OIB, OIB is preferred for our study, since MORB likely represents a broader averaging of the upper mantle, which produces an artificial peak at zero time. In contrast, OIB is expected to represent samples of smaller regions that retain the heterogeneity of the mantle, and more thoroughly separate out enriched and depleted domains. As shown in Figure 2, these two curves, based on ^{4}He/^{3}He and Nb/Th, give the same overall trend of depletion rate, namely a peak in the Neoarchean, a minimum at about 1.0 Ga, and another peak in the Phanerozoic. In the case of Nb/Th the crustal growth curve is a net curve that includes the effects of juvenile crust production, as well as the recycling of crust back into the mantle by such processes as subduction erosion, sediment subduction, or foundering of arc lower crust (*S3*). However, since these loss mechanisms are likely proportional to subduction flux, we assume that Nb/Th remains a reasonable proxy for subduction flux. In the case of the ^{4}He/^{3}He ratio, recycling is not a problem, since helium is degassed after arc magmatism and not recycled back into the mantle.

Thermal history calculation

In the thermal history calculation (Figure 3), we solve the global heat balance equation (*S4*):

$$dT/dt = (H(t) - Q(t))/c \qquad (1)$$

where c is global heat capacity (7×10^{27} J/°K), $T(t)$ is internal mantle temperature, $H(t)$ is radioactive heat production (using values in Table 1 of Reference *S5*), and $Q(t)$ is heat loss. Following Reference *S5*, for plate tectonics, *Q(t)* can be approximately expressed as $Q = aT^b$, here a and b are two constants. This is based on the well known scaling $Nu \propto Ra^\beta$, where *Nu* and *Ra* are Nusselt number and Rayleigh number respectively. We use a=1.35x10^{-19}, b=6.52, which correspond to β=0.3 and an activation energy 300 kJ/mol in the expression for the temperature dependence of viscosity (*S5*). To approximate intermittent plate tectonics, we define a plate-tectonic efficiency function, *P(t),* taking on values between 0 and 1, with 1 corresponding to "full" plate tectonics and 0 corresponding to the absence of plate tectonics. We thus redefine heat loss as $Q(t) = aT^b(t)P(t)$. In doing so, we implicitly assume that $Q<<H$ in the absence of plate tectonics. We furthermore assume that *Q(t)* is proportional to the subduction flux, $F_s(t)$, which is, in turn, proportional to the mantle depletion rate, *C(t)* (Figure 2). Thus $Q(t) = aT^b(t)P(t) = kC(t)$, where k is an arbitrary constant. Rather than use *C(t)* directly to specify *Q(t)*, we instead prefer to retain the explicit dependence of *Q* on *T* and use *C(t)* only to determine *P(t)*. While it is possible to write *P(t)* as

$$P(t) = kC(t)/aT^b(t) \tag{2}$$

we take a simplified approach by assuming the two peaks in *C(t)*, at the present and at t=2.5 Ga (Figure 2), correspond to full plate tectonics ($P=1$). The denominator in Eq. 2 accounts for the expected increase in peak height with age, and we scale *C(t)* accordingly. The value of *P(t)* at the 1 Ga minimum is constrained to be 0.1 (i.e. permitting about 10% of the present-day subdution flux corresponding to ~5000 km of subduction length). *P(t)* is shown in Figure S1. The resulting *Q(t)* is then used in (1), which is solved numerically with the initial conditions (at the present) of T_o=1350°C and $Q_0=\gamma_0 H_0$, where γ_0 is the present-day Urey ratio, taken to be γ_0 = 0.3 (Figure 3). Also shown for comparison are thermal histories for *P(t)=1*, with γ_0=0.3 and γ_0=0.7.

Figure Captions

Figure S1. Plot of plate tectonic efficiency function *P(t)* used in thermal calculations, based on the curves in Figure 2. *P(t)* was constrained to have the peaks at the present and at 2.5Ga both corresponding to *P(t)=1.* In addition, the minimum in *P(t)* at ~1 Ga was constrained to be at least 0.1 and the peak in *P(t)* in the Phanerozoic was continued to the present.

Figure S2. Plot of magmatic flux (*S6*) vs convergence velocity (*S7*) for several subduction zones in the Pacific. Shown is best-fit line assuming that line must pass through (0,0). Slope is 1.1 km^3/km^2.

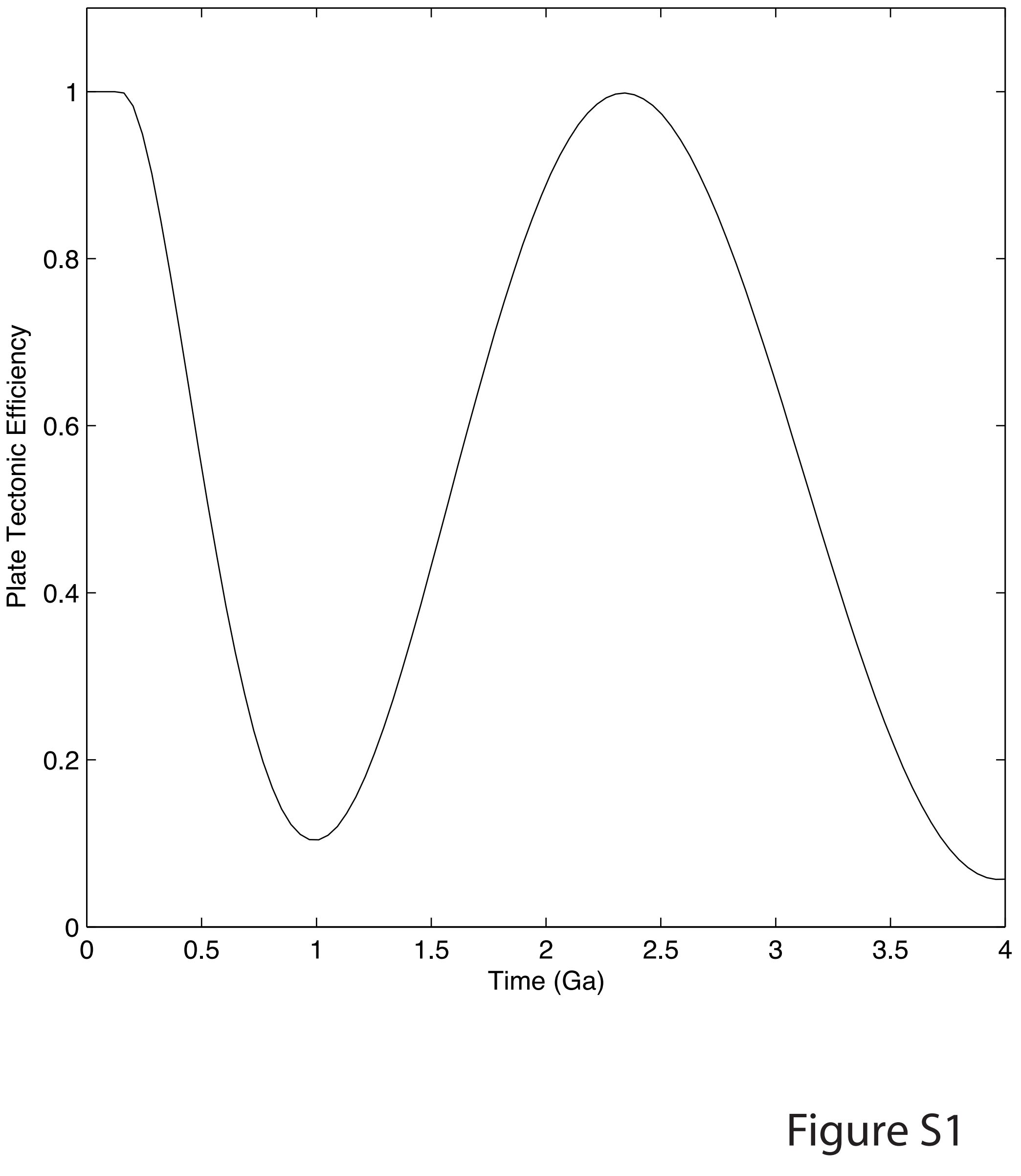
Plate Tectonic Efficiency
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (Ga)

Figure S1

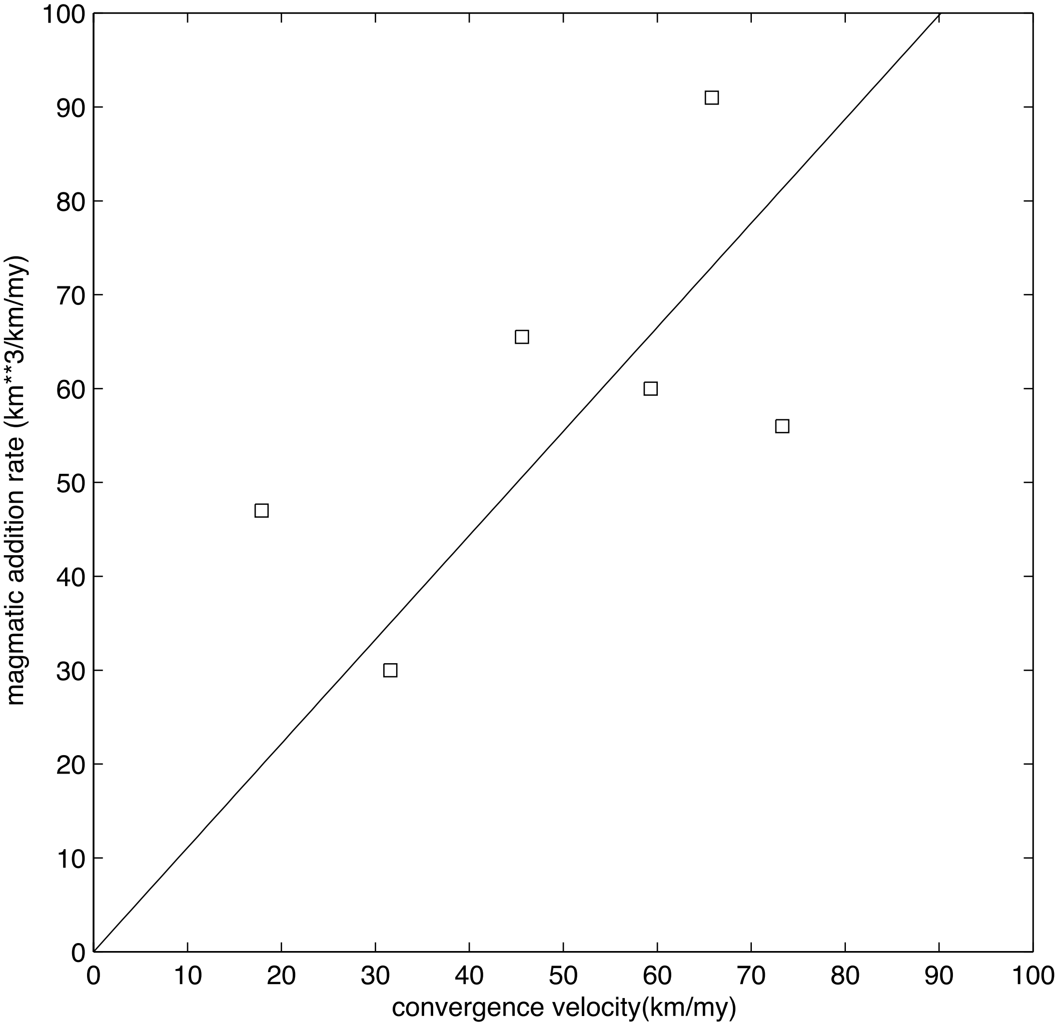
magmatic addition rate (km**3/km/my)
convergence velocity(km/my)
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80
90
100

Figure S2

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