

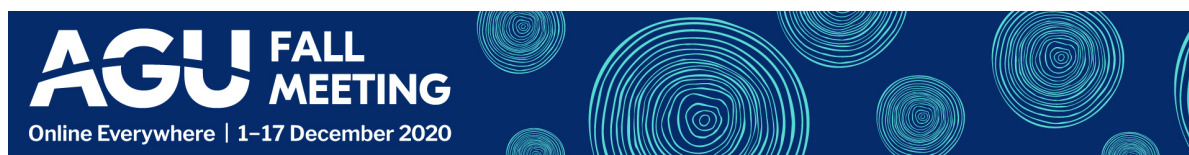
Weaker lithospheric dripduction into Archean TTG crust formation

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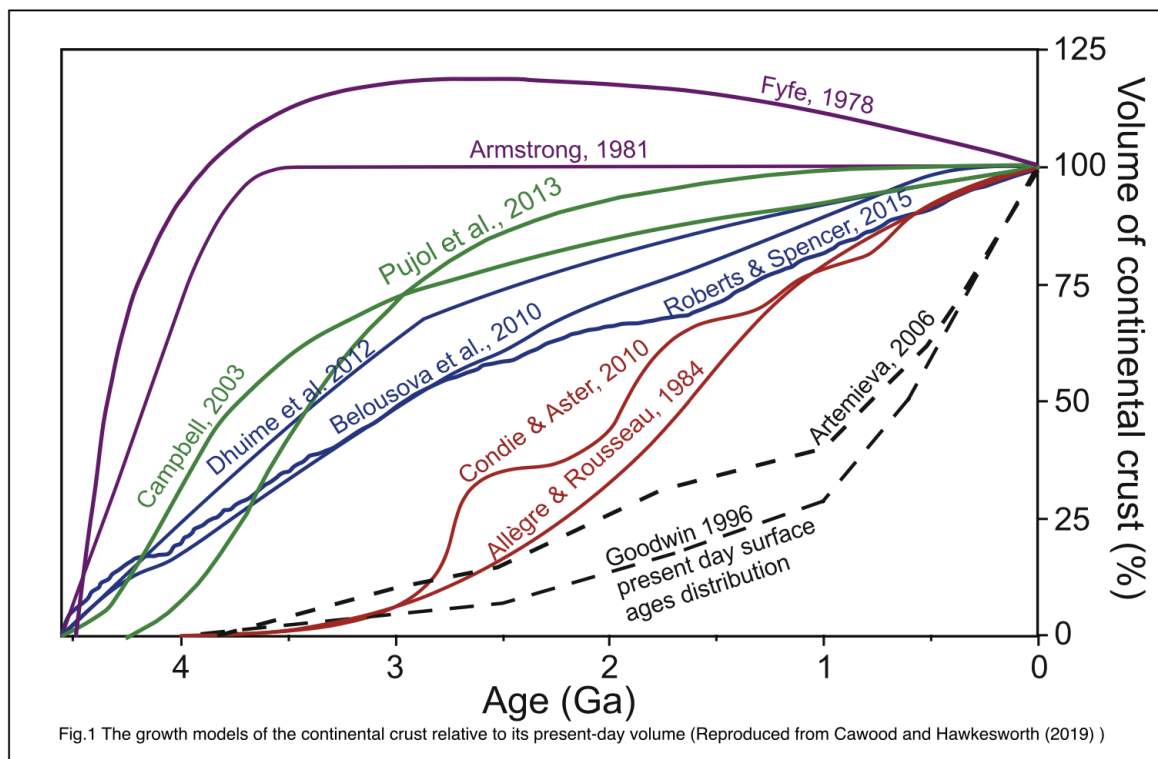
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INTRODUCTION

- Lithospheric yield stress is a key parameter in controlling tectonic processes, remains poorly constrained for the Archean lithosphere.
- We calculate yield stress for a range of conditions appropriate to the Archean Earth, including hotter mantle potential temperatures and a range of Moho temperatures.
- This range of conditions are evaluated for generating felsic, tonalite-trondhjemite-granodiorite (TTG), crust with the results bench marked against the preserved rock record.
- Expected total TTG volume is 70% of the present continental volume which cast into differentiation index (DI) of 1.7 % and the expected medium pressure(MP-) to Low pressure (LP-) TTG ratio is 3:1. Please refer Gunawardana et al., 2020 for further details.

The growth models for continental crust (Reproduced from Cawood and Hawkesworth., 2019)



METHODOLOGY

- 2D high resolution numerical geodynamic modelling techniques are used in Underworld2 software platform.
- Mass, Momentum and Energy equations are solved using particle in cell method.

$$\vec{\nabla} \cdot \vec{u} = 0 \quad (1)$$

$$-\vec{\nabla} \cdot P + \vec{\nabla} \cdot [\eta(\partial_i u_j + \partial_j u_i)] = -\rho \vec{g} \quad (2)$$

$$\partial_t T + \vec{u} \cdot \vec{\nabla} T = \nabla^2 T + H \quad (3)$$

Viscosity

- Arrhenius viscosity and plastic yielding are applied to the model.

$$\eta_T = \eta_o \exp \left[\frac{E + d.V}{T + 1} - \frac{E}{2} \right] \quad (6)$$

$$\sigma_Y = \sigma_Y^o + d\sigma_Y' \quad (7)$$

Density

- Temperature dependent density is applied following Sizova et al., 2015.

$$\rho = \rho_o [1 - \alpha \Delta T] \quad (8)$$

$$\rho_{eff} = \rho_{solid}(1 - M) + \rho_{melt}M \quad (9)$$

$$\rho_{solid} = \rho_o [1 - \alpha \Delta T] (1 + coef_{res} + coef_{phase}) \quad (10)$$

Melt generation and depletion

- Melt fraction and depletion are calculated following Sizova et al., 2015.

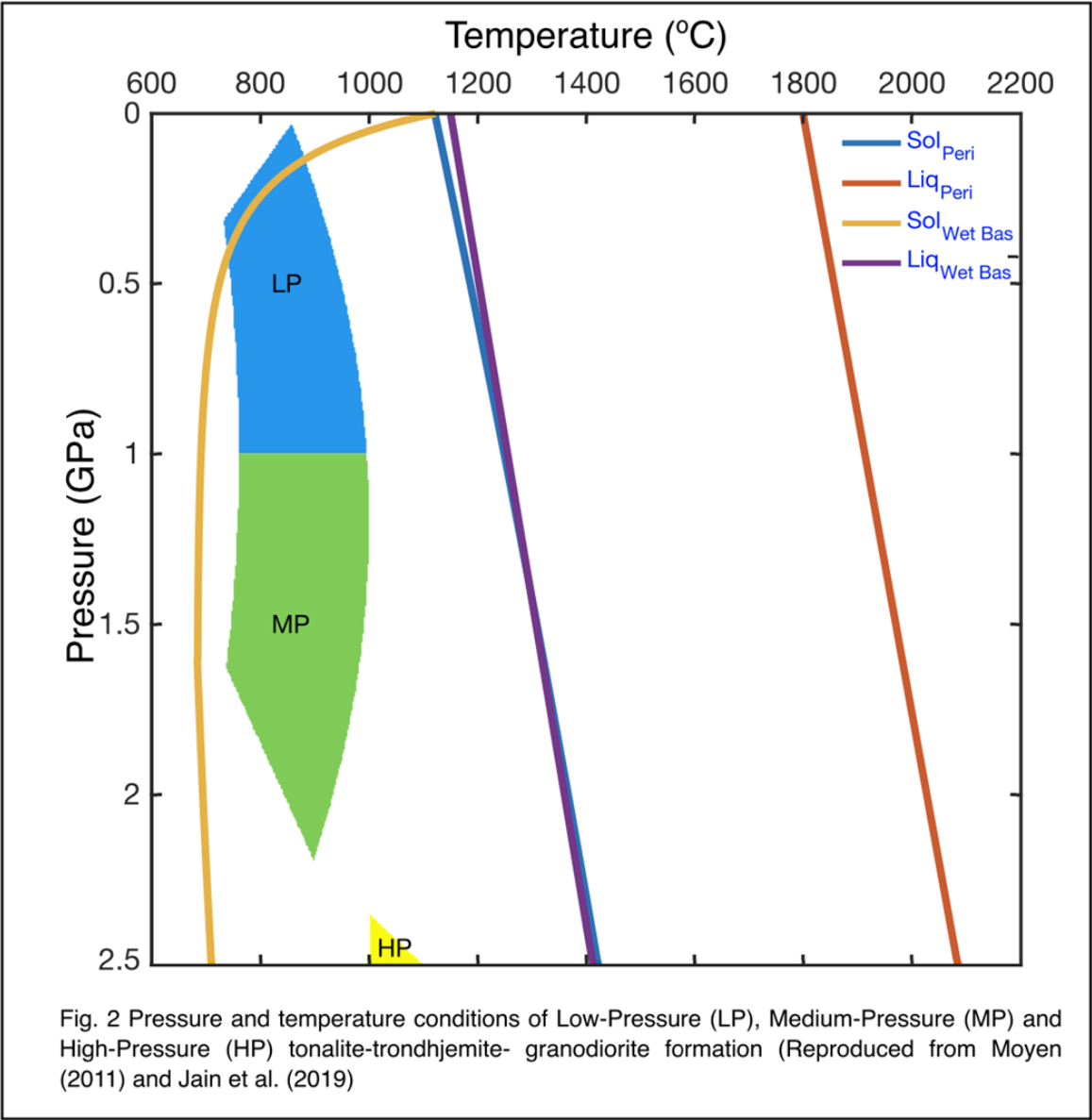
$$M_o = \begin{cases} 0, & T_1 < T_{solidus} \\ \frac{T_1 - T_{solidus}}{T_{liquidus} - T_{solidus}}, & T_{solidus} < T_1 < T_{liquidus} \\ 1, & T_1 > T_{liquidus} \end{cases} \quad (4)$$

$$M = M_o - \sum_n M_{ext} \quad (5)$$

Melt classification

- Melt is classified based on the source rock P-T conditions

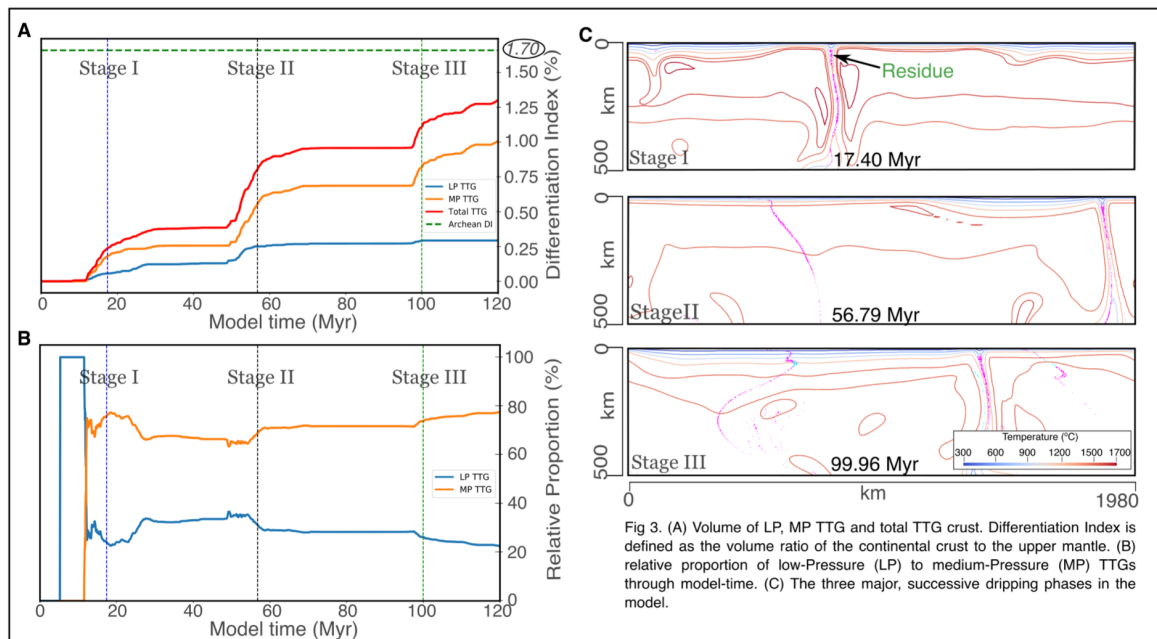
P-T conditions for various TTG types



RESULTS

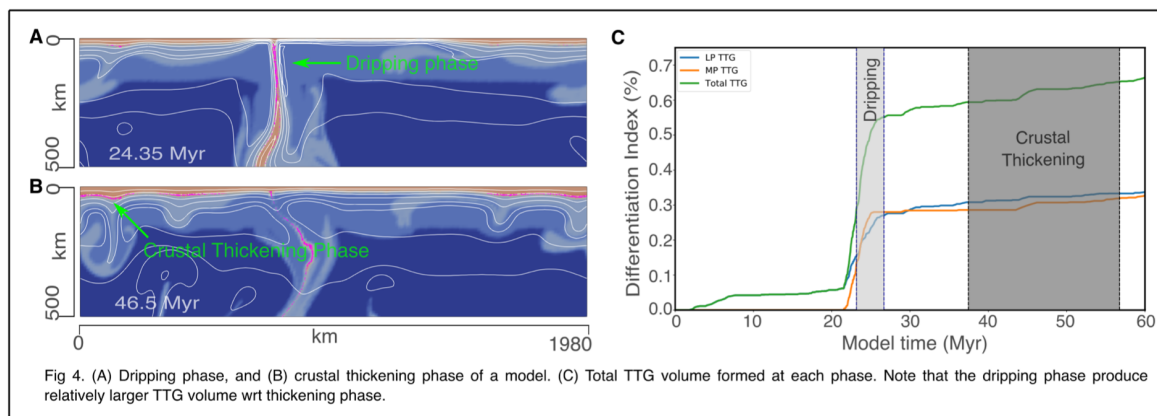
- Lithospheric yield stress slightly lower than the present-day Earth values (i.e. < 100 MPa) generates TTG melt volumes equivalent ~70 % of present continental volume within few hundreds of Ma.
- Furthermore, weaker lithosphere together with the dominance of dripping can also account for the large abundance of MP-TTGs relative to the LP-variant within the early Archean rock record.

Total melt volume and relative proportion of TTGs for 3 dripping stages of a model with $T_p = 1600^\circ\text{C}$, $T_{\text{moho}} = 600^\circ\text{C}$ and Yield stress = 50 MPa. (Reproduced from Gunawardana et al., 2020)



- In particular, large volumes of TTG melts form in the tails of lithospheric drips. Melting occurs profusely within the thinner portions of the drips as these regions are more efficiently heated by the enclosing hotter mantle.
- In contrast, only limited melting occurs in regions of thickened crust, in part because the weaker lithosphere cannot sustain crustal thickening for long time periods, resulting in its removal through drips.

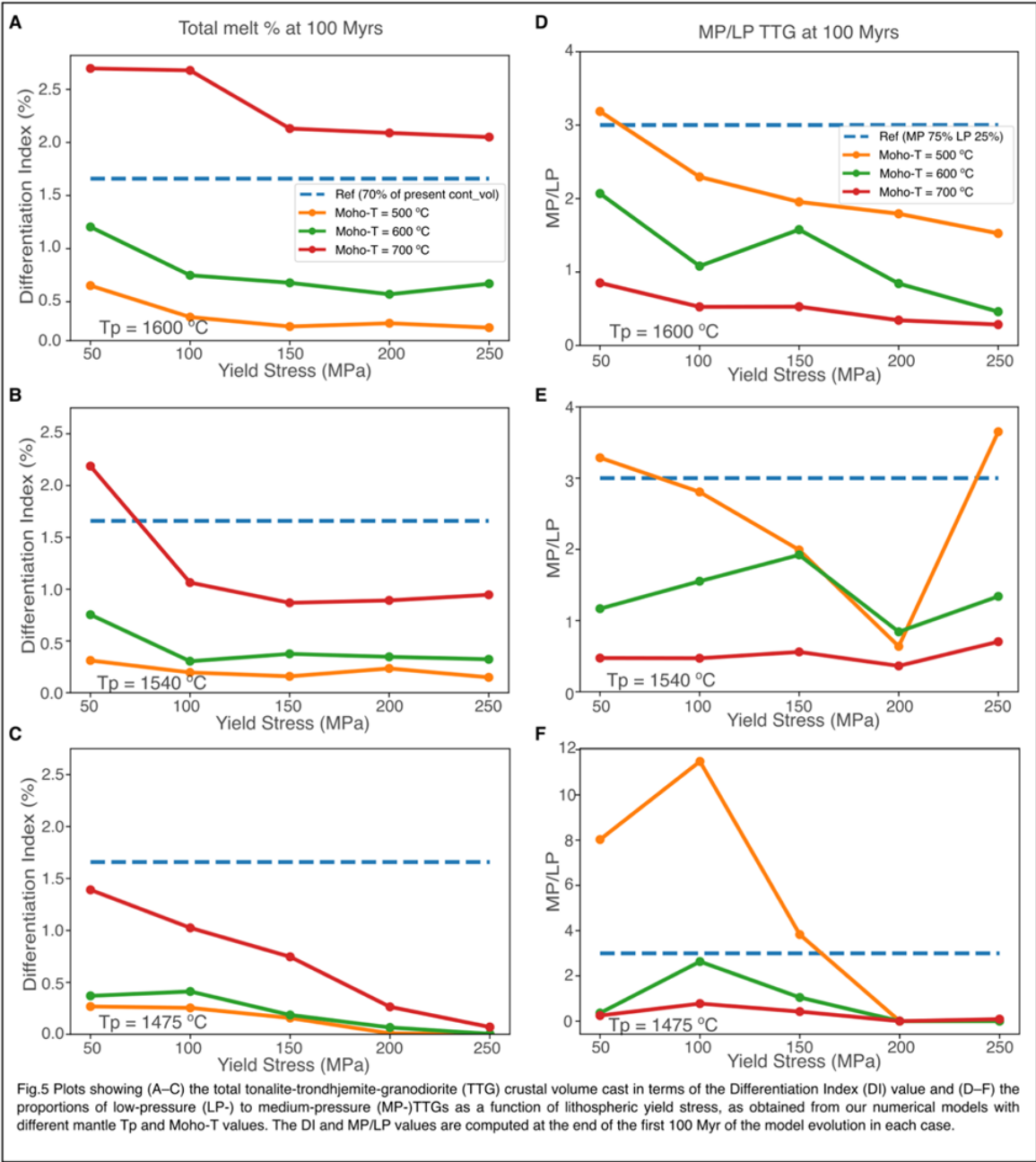
TTG formation between basaltic crustal dripping vs thickening phase (Reproduced from Gunawardana et al., 2020)



RESULTS...

- Furthermore, the model results show that TTG production and the resulting Differentiation Index (DI) values increase with the lowering of lithospheric yield strength for any given mantle and Moho temperature conditions.

Total tonalite-trondhjemite-granodiorite (TTG) crustal volume cast in terms of the Differentiation Index (DI) and proportions of low-pressure (LP-) to medium-pressure (MP-)TTGs as a function of lithospheric yield stress, as obtained from our numerical models with different mantle *T_p* and Moho-*T* values.(Reproduced from Gunawardana et al., 2020)



CONCLUSION

- The preserved record of early Archean felsic crust is more consistent with the presence of weaker lithosphere during active tectonism at those times.
- Tectonic activity involving such weaker lithosphere atop hotter mantle would have led to the production of voluminous TTG melt prior to $\sim 3\text{Ga}$, consistent with the inference of numerous crustal growth models.
- Our study further shows that TTG production may have dominantly occurred within mafic crustal drips, whereas crustal thickening made an only subordinate contribution unless the crust was significantly thicker.
- The low yield stress facilitated the drips to grow in length up to few hundreds of km and keeping them stable over tens of Myr.
- Furthermore, weaker lithosphere together with the dominance of dripping can also account for the large abundance of MP-TTGs relative to the LP-variant within the early Archean rock record.
- Our models highlight the dominance of non-plate tectonic mechanisms in producing TTGs under the conditions that operated on the hotter Archean Earth.

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ABSTRACT

Lithospheric yield stress is a key parameter in controlling tectonic processes. We calculate yield stress for a range of conditions appropriate to the Archean Earth, including hotter mantle potential temperatures and a range of Moho temperatures using 2D high resolution numerical geodynamic modelling techniques. This range of conditions are evaluated for generating felsic, tonalite-trondhjemite-granodiorite (TTG), crust with the results bench marked against the preserved rock record. The model results indicate that lithospheric yield stress slightly lower than the present-day Earth values (i.e. < 100 MPa) generates TTG melt volumes similar to those preserved in the rock record. In particular, large volumes of TTG melts form in the tails of lithospheric drips. Melting occurs profusely within the thinner portions of the drips as these regions are more efficiently heated by the enclosing hotter mantle. In contrast, only limited melting occurs in regions of thickened crust, in part because the weaker lithosphere cannot sustain crustal thickening for long time periods, resulting in its removal through drips. Our models highlight the dominance of non-plate tectonic mechanisms in producing TTGs under the conditions that operated on the hotter Archean Earth.

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