Supplementary Information

The SPH code we use utilizes 100,000 to 1M particles in a parallel shared-memory environment using OpenMP/Xeon Phi to model the behavior of a material with a Tillotson equation of state (EOS), under differing rotation rates.
To avoid particle clustering at high pressures, the SPH method uses a spiky kernel (W_{spiky}) to solve for pressure, of the form

$$W_{spiky}(\boldsymbol{r},h) = \frac{15}{\pi h^6}\begin{cases}(h-r)^3 & 0 \le r \le h \\ 0 & \text{Otherwise}\end{cases}$$

(Equation S.1)

The gradient term is of the form:

$$\nabla W_{spiky}(\boldsymbol{r},h) = \frac{45}{\pi h^6}\frac{\boldsymbol{r}}{\|r\|}(h-r)^2$$

(Equation S.2)

The particle mass scales with Me/N_particles, and the smoothing kernel radius selected to fit Earth's internal pressure distribution.

The Tillotson equation of state has the form:

$$P_c = \left(a + \frac{b}{\frac{u}{u_0\eta^2}+1}\right)u\rho + A\mu + B\mu^2$$

(Equation S.3 for Tillotson condensed)

$$P_e = au\rho + \left(\frac{bu\rho}{\frac{u}{u_o\eta^2}+1} + A\mu\exp\left(-\alpha(\eta^{-1}-1)\right)\right)\exp(-\beta(\eta^{-1}-1)^2)$$

(Equation S.4 for Tillotson expanded)

$$P_t = \frac{(P_e(u-u_s) + P_c(u'_s-u))}{(u'_s-u_s)}$$

(Equation S.5 for Tillotson transitional)

The condensed form (P_c) is employed when the density $\rho > \rho_0$, or when the internal energy $u < u_s$, where ρ_0 and u_s are the reference density and internal energy respectively. The terms $\eta = \rho/\rho_0$ and $\mu = \eta - 1$. The terms a, b, A, B, ρ_0, u_0, u_s, u_s', α and β are material properties outlined in Table S1. The expanded form (P_e) is employed when $\rho < \rho_0$, and $u < u_s'$, and the transitional form ensures a smooth transition between the two regimes, and is applied when $u_s < u < u_s'$ and $\rho > \rho_0$.
The material terms for our model are for a "chrondritic Earth" (an olivine-iron mix) pre core formation, and for an olivine mantle and iron core post-differentiation, outlined in Table S1.

	Olivine	Iron
ρ_a (kg/m3)	3500	7860
K (GPa)	131	128
B (GPa)	49	105
a	0.5	0.5
b	1.4	1.5
α	5	5
β	5	5
U_0 (MJ/kg)	550	9.5
E_s (MJ/kg)	4.5	1.42
E_{sp} (MJ/kg)	14.5	8.45

Table S.1 Material properties for Tillotson EOS (adapted from Marinova et al., 2011).

We use a brute-force approach (Xeon-Phi) and tree-based approaches for the N-body gravity calculation, and solve the mass, momentum and energy equations:

$$\rho_i = \sum_{j=1}^{N} m_j W_{ij}$$

(Equation S.6 Mass)

Here ρ_i is the density of particle i, m_j is the mass of the jth particle, and W_{ij} the kernel at the position of j.

$$\frac{dv_i}{dt} = -m \sum_{j=1}^{N} \left(\frac{P_j}{\rho_j^2} + \frac{P_i}{\rho_i^2} + \Pi_{ij} \right) \nabla_i W(r_{i,j}, h) - G \sum_{j=1}^{N} \frac{m(r_{ij})}{r_{ij}^2} \hat{r}_{ij} + F_i^{visc}$$

(Equation S.7 Momentum)

Here v_i is the velocity, G the gravitational constant, Π_{ij} an artificial velocity term to mediate shocks, and F^{visc} a conventional viscosity. Following Liu and Liu (2003), and using the superscripts α and β to denote coordinate directions (and not Tillotson material properties, as previously), F_{visc} is of the form:

$$F_{visc} = m \sum_{j=1}^{N} \left(\frac{\mu_i \varepsilon_i^{\alpha\beta}}{\rho_i^2} + \frac{\mu_j \varepsilon_j^{\alpha\beta}}{\rho_j^2} \right) \nabla_i W(r_{i,j}, h)$$

(Equation S.8)

Here μ_i is the dynamic viscosity, and $\varepsilon_i^{\alpha\beta}$ is the shear strain rate, given by:

$$\varepsilon_i^{\alpha\beta} = \sum_{j=1}^{N} \frac{m_j}{\rho_j} v_{ji}^{\beta} \frac{\partial W_{ij}}{\partial x_i^{\alpha}} + \sum_{j=1}^{N} \frac{m_j}{\rho_j} v_{ji}^{\alpha} \frac{\partial W_{ij}}{\partial x_i^{\beta}} - (\frac{2}{3} \sum_{j=1}^{N} \frac{m_j}{\rho_j} v_{ji} \cdot \nabla_i W_{ij}) \delta^{\alpha\beta}$$

(Equation S.9)

The artificial viscosity is of the form:

$$\Pi_{ij} = \begin{cases} \dfrac{-\alpha_{\Pi} \bar{c}_{ij} \phi_{ij} + \beta_{\Pi} \phi_{ij}^2}{\bar{p}_{ij}}, & (v_{ij} \cdot x_{ij} < 0) \\ 0, & (v_{ij} \cdot x_{ij} \geq 0) \end{cases}$$

(Equation S.10)

Here α_{Π} and β_{Π} are coefficients (equal to 0 and 2, respectively, as we only retain the shock penetration effects, shear viscosity being treated as per S.8). $\bar{c}_{ij}$ is the average sound speed of particles i and j, $\bar{p}_{ij}$ their average density, and

$$\phi_{ij} = \frac{h_{ij} v_{ij} \cdot x_{ij}}{|x_{ij}|^2 + \varphi^2}$$

(Equation S.11)

φ is set to 0.1h to prevent instabilities at short distances.

The energy equation is then given by:

$$\frac{du_i}{dt} = 0.5 \sum_{j=1}^{N} \left(\frac{P_j}{\rho_j^2} + \frac{P_i}{\rho_i^2} + \Pi_{ij} \right) v_{ij}^{\beta} \nabla_i W(r_{i,j}, h) + \frac{\mu_i}{2\rho_i} \varepsilon_i^{\alpha\beta} \varepsilon_j^{\alpha\beta}$$

(Equation S.12 Energy)

Particles are advanced using a velocity-verlet scheme, and benchmarked against the 1D Shock Tube problem – a well-known benchmark in the SPH community (eg. Sod, 1978; Monaghan and Gingold, 1983, Hernquist and Katz, 1989) for which an iterative analytical solution exists.

Supplementary references

Hernquist, L., & Katz, N. (1989). TREESPH-A unification of SPH with the hierarchical tree method. *The Astrophysical Journal Supplement Series*, *70*, 419-446.

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Monaghan, J. J., & Gingold, R. A. (1983). Shock simulation by the particle method SPH. *Journal of computational physics*, *52*(2), 374-389.

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