Destabilization of methane clathrate hydrate by meteorite impacts on present-day Mars

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→ Study of the capacity of small-sized impact craters to thermally penetrate the Martian ground and release methane through the dissociation of subsurface clathrate reservoirs.

→ Only small impactors (D~1-2 m), representative of the present-day conditions, are considered.

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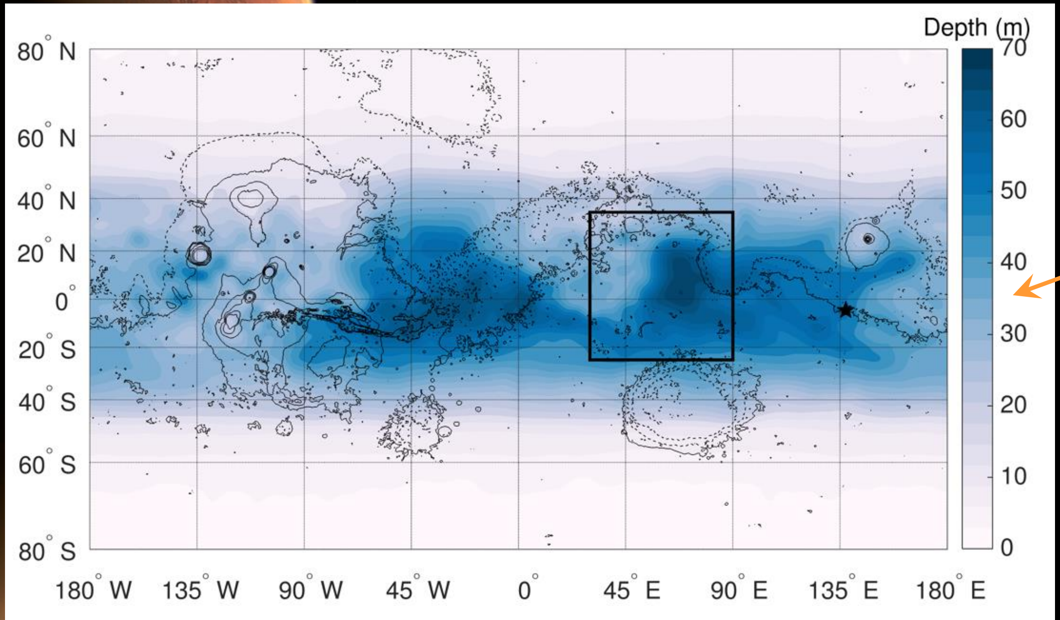
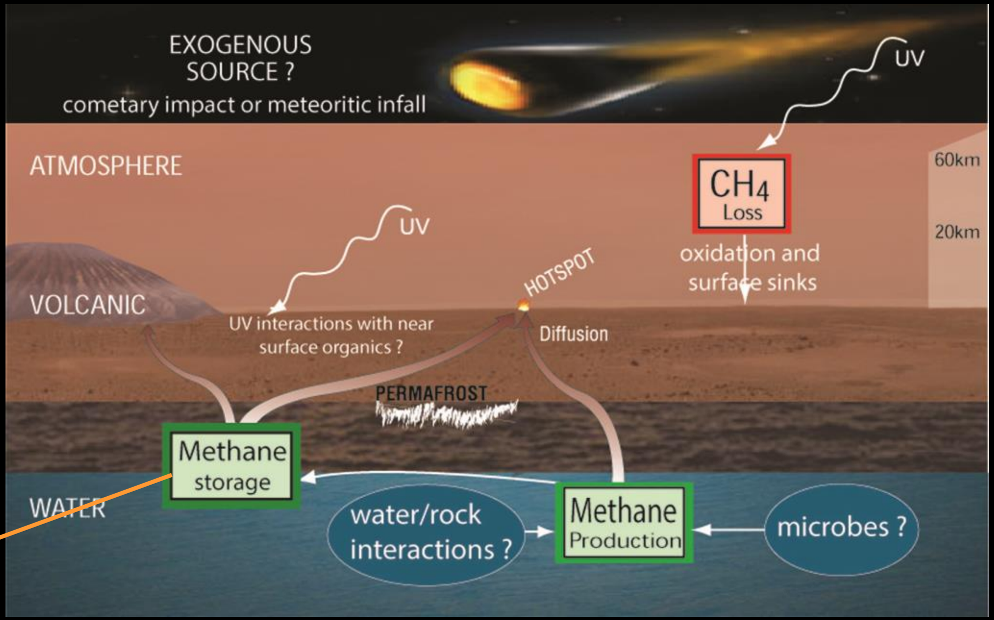
- CH_4-rich clathrates are stable close to the surface with a stability zone strongly dependent on the average annual surface temperature.



Depth (m) of the top of clathrate stability zone in present-day martian subsurface for CH_4-rich clathrates formed from a gas phase with 90% of methane (Gloesener et al., 2020).



Potential sources and sinks of methane on Mars. Credits: NASA/JPLCaltech, SAM/GSFC.

- A one-dimensional finite difference thermal model of the subsurface is used to calculate the depth of stable methane clathrate hydrates.

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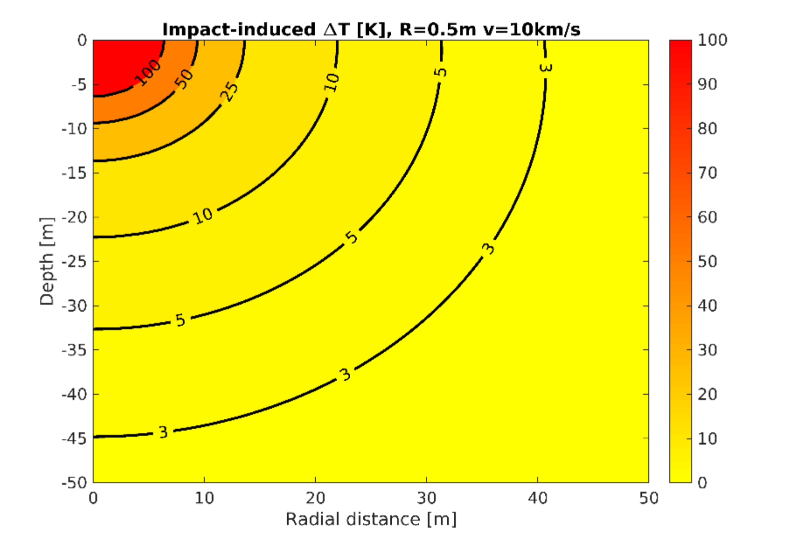
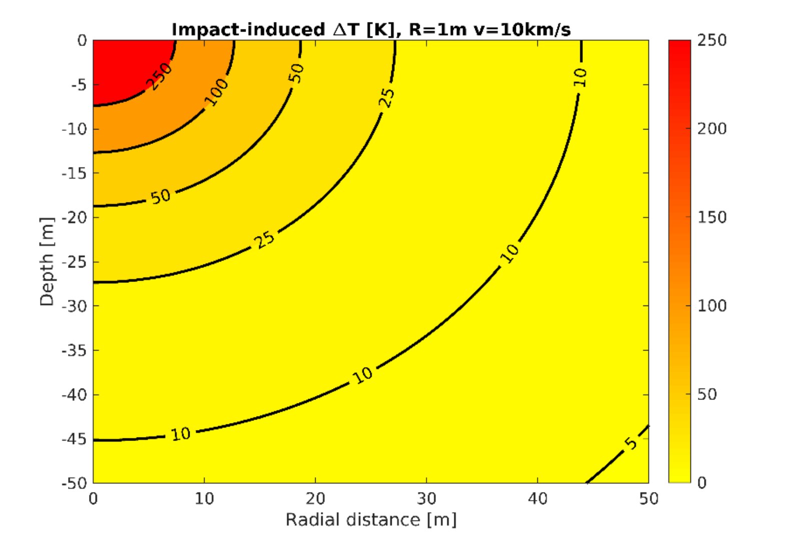
- The impact-induced heat is calculated using the Murnaghan equation of state similarly to Schwenzer et al. (2012).
- Increase of temperature in the subsurface at the time of impact is:
  - > 10° for depths < 22 m (R=0.5m and v = 10 km/s).
  - > 10° for depths < 45 m (R=1m and v = 10 km/s).





Parameters	
Impactor radius R	0.5 – 1 m
Impact velocity v	10 km/s
Impact angle	45°
Impactor/target density	2600 kg/m^3 (basalt)
Decay exponent	-1,025
Heat capacity	800 J kg^{-1} K^{-1}
Adiabatic bulk modulus at zero pressure	19.3 x 10^9
Pressure derivative of the bulk modulus	5.5 (basalt)

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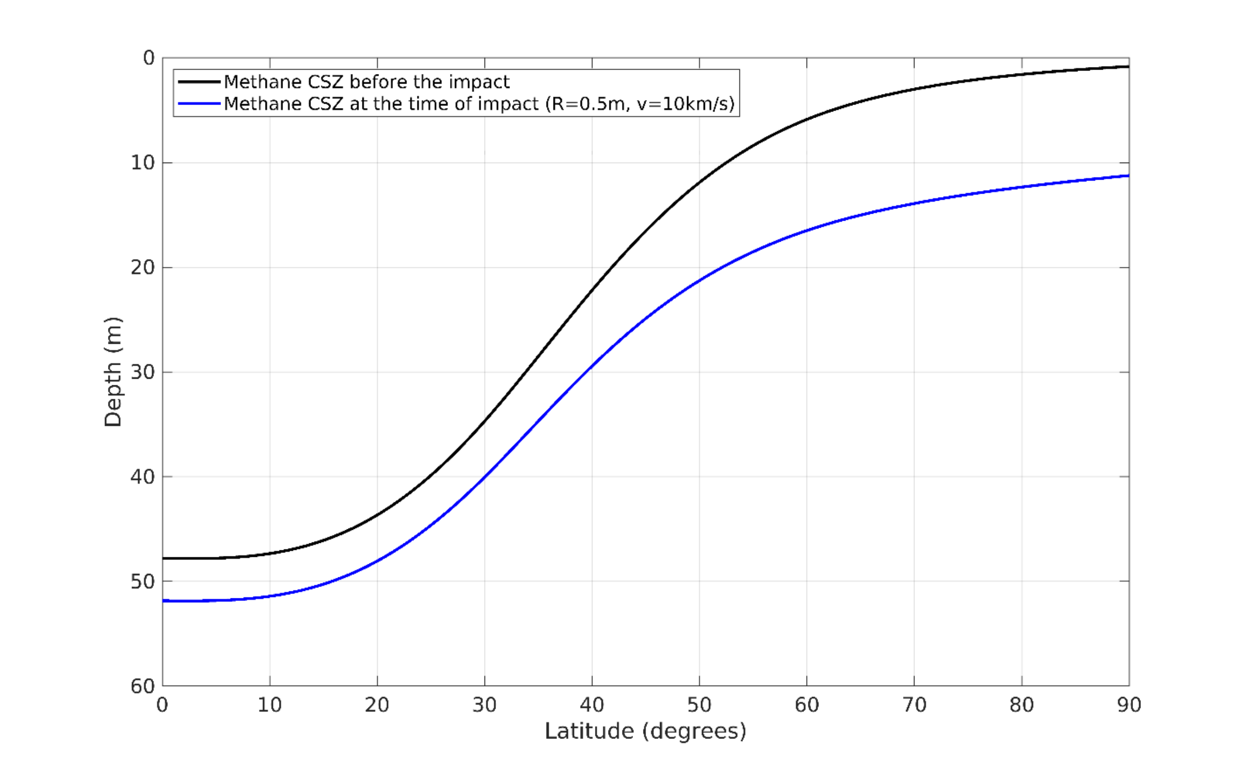

Top of the methane clathrate stability zone (CSZ) in the Martian subsurface and its variation at the time of impact. A thermal conductivity of 1.5 W m^{-1} K^{-1} and annual mean surface temperatures have been considered.

- Small impacts can potentially affect clathrates at all latitudes if those CH_4 reservoirs are located near the top of their stability field.
- Meteorite impacts occuring at high latitude allow the destabilization of a thicker clathrate layer than at lower latitude since clathrates are closer to the surface near the poles.
- Near the equator, a minimum impactor radius of 0.33 m with a velocity of 10 km/s is required to allow destabilization of methane clathrates.

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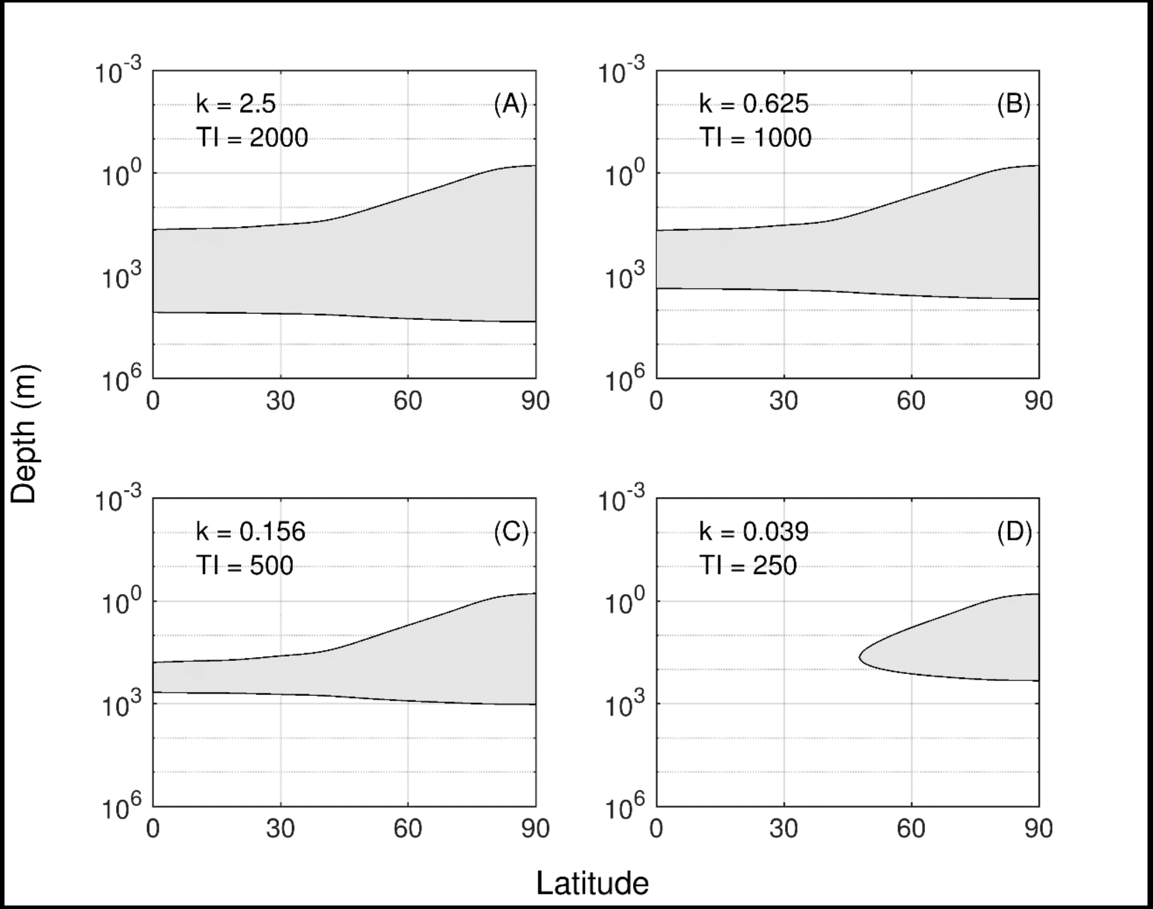
- In equatorial regions, where methane was reported on Mars, small impacts can thermally destabilize clathrate subsurface layers of several meters thick for impactor radius R > 0.33 m and a velocity v = 10 km/s.

- Future studies should involve:
  - The effect of pressure and the removal of material at the surface.
  - Various compositions for the Martian crust, which will affect the clathrate stability zone (see figure).
  - 2D evolution of the subsurface temperatures after the impact.



Stability zone of simple CH_4 clathrate in the Martian crust for different thermal properties in the subsurface model corresponding to thermal inertia (TI) ranging from 250 to 2000 J m^{-2} K^{-1} $s^{-1/2}$. The volumetric heat capacity *c* is kept constant (1.6×10^6 J K^{-1} m^{-3}) while the thermal conductivity k is changed to 2.5 (A), 0.625 (B), 0.156 (C) and 0.039 W m^{-1} K^{-1} (D) respectively.

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Acknowledgements

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