SURVIVAL OF TERRESTRIAL MATERIAL IMPACTING THE LUNAR SURFACE

Samuel H. Halim[1], Ian A. Crawford[1], Gareth S. Collins[2], Katherine H. Joy[3]

[1] Department of Earth and Planetary Sciences, Birkbeck University, University of London, Malet St., London WC1E 7HX.
[2] Department of Earth Science & Engineering, Imperial College London, Kensington, London SW7 2AZ.
[3] School of Earth and Environmental Sciences, University of Manchester, Oxford Rd., Manchester M13 9PL.

ePoster Abstract

Birkbeck UNIVERSITY OF LONDON

Highlights

- **Projectile peak shock temperature (peakT) is higher than expected** vs. corresponding peak shock pressure (peakP).
- In scenarios where **projectile porosity is high,** peakP seems to be favourable to survival but causes a **significant increase in peakT.**
- **Survivability** of terrestrial meteorites is **expected to be less than previous modelling** work for higher velocity impacts (5 km s^{-1}).
- **Survival in significant proportions** is still expected when impacting at lower velocities **into highly porous lunar targets** (>50% porous).

Introduction

- During the Late Heavy Bombardment (LHB), Earth would have experienced many giant impacts, **ejecting terrestrial material** at velocities great enough to surpass escape velocity and **take up Moon-crossing orbits** (Figure 1).
- **Ejecta could be preserved on the lunar surface** as terrestrial meteorites, if they survive impact [1-3].
- Lack of atmosphere, plate tectonics, and low surface gravity enhance the likelihood that **the Moon might preserve a record of the early Earth.**
- In some regions of the lunar surface, as much as **510 kg km^{-2} of terrestrial material** may have impacted [1].
- This work aims to **assess survivability of terrestrial meteorite projectiles impacting the lunar surface** by extracting **temperature and pressure data** from hydrocode models.
- Do we already have a record of terrestrial meteorites on the Moon?

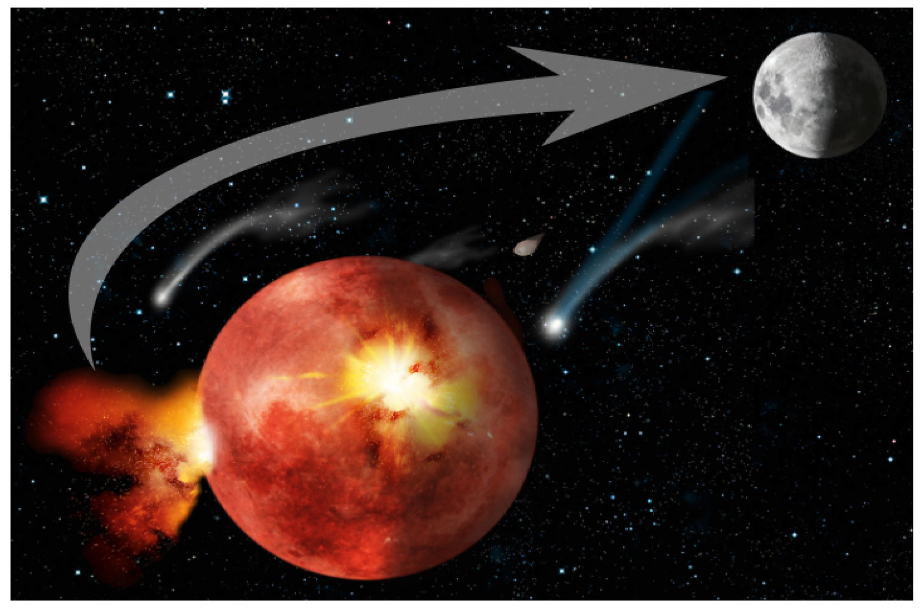


Figure 1 | Terrestrial ejecta transfer to the lunar surface.

Artists representation of giant impacts into the Earth during the LHB and the transfer of ejecta to the Moon.

Adapted from illustration by Tim Wetherell - Australian National University.

Methods

Using iSALE-2D [4,5], this work aims to update and improve upon the simulations conducted using ANSYS AUTODYN [6]. We simulated **sandstone projectiles** vertically impacting a **basalt target layer at 5 km s^{-1} and 2.5 km s^{-1}**. The **porosity of the projectile and target were varied** at set intervals (Table 1) to investigate the **effect on peak pressures and temperatures**, in order to assess survivability of a range of sedimentary materials and the possible organic constituents within. Projectile shape was also considered but not included here.

The Models

5 km s^{-1}				2.5 km s^{-1}			
Model	Shape	Projectile porosity	Target porosity	Model	Shape	Projectile porosity	Target porosity
A	Sphere	Solid	Solid	I	Sphere	Solid	Solid
B	Sphere	Solid	30%	J	Sphere	Solid	30%
C	Sphere	Solid	50%	K	Sphere	Solid	50%
D	Sphere	Solid	70%	L	Sphere	Solid	70%
E	Sphere	10%	Solid	N	Sphere	10%	Solid
F	Sphere	20%	Solid	M	Sphere	20%	Solid
G	Sphere	30%	Solid	O	Sphere	30%	Solid
H	Sphere	40%	Solid	P	Sphere	40%	Solid

Table 1 | Parameters for the models run at 5 and 2.5 km s^{-1}

Model setup:

- 2D cylindrical half-space
- 0.5 m diameter projectile
- Lunar gravity (1.62 m s^{-2})
- 50 **C**ells **P**er **P**rojectile **R**adius (**CPPR**)
- Tracers in every cell, track PeakP and PeakT
- Run until peakP/T stop increasing (1.5 ms)

Survivability: PeakP vs. PeakT

Survivability has routinely been based upon threshold peak shock pressures, but **shock temperatures must also be considered** to fully understand projectile survival. This reliance on pressure as a proxy for survivability could lead to an overestimation on the fraction of survived material in lower hyper-velocity impacts.

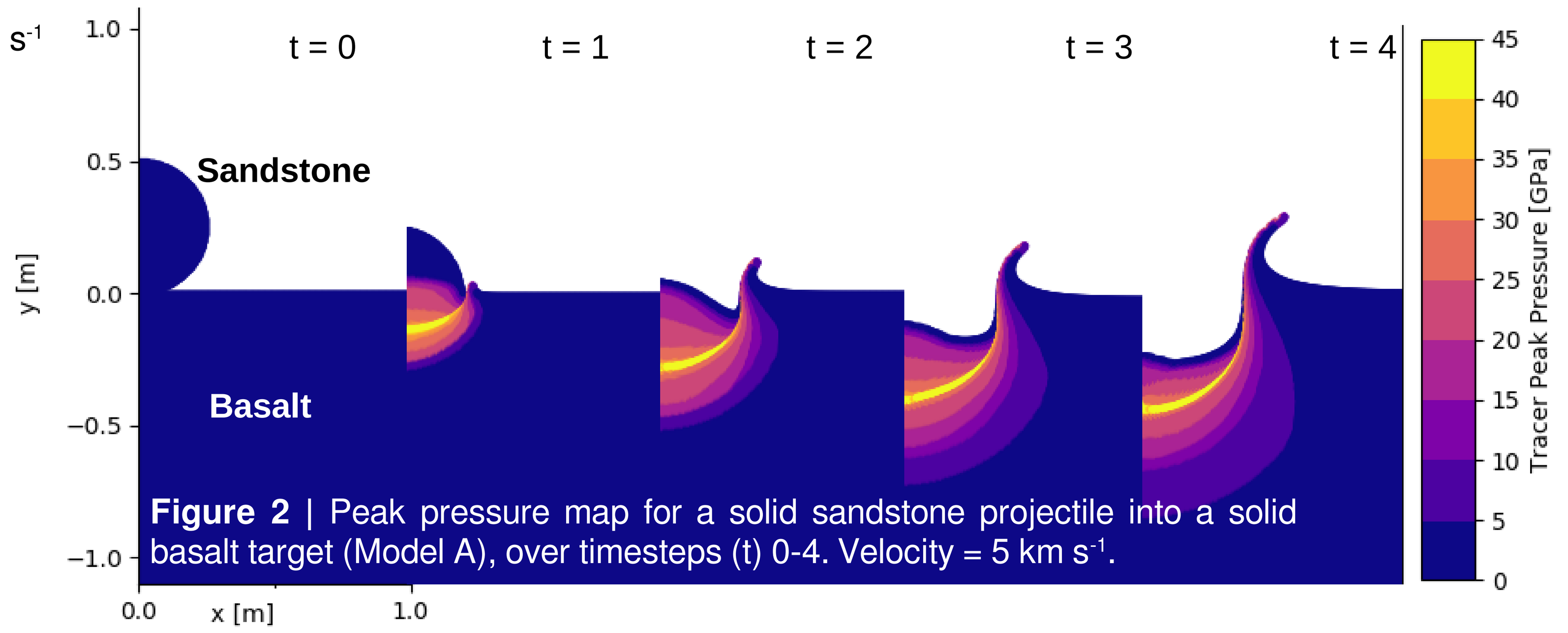


Figure 2 | Peak pressure map for a solid sandstone projectile into a solid basalt target (Model A), over timesteps (t) 0-4. Velocity = 5 km s^{-1}.

Results

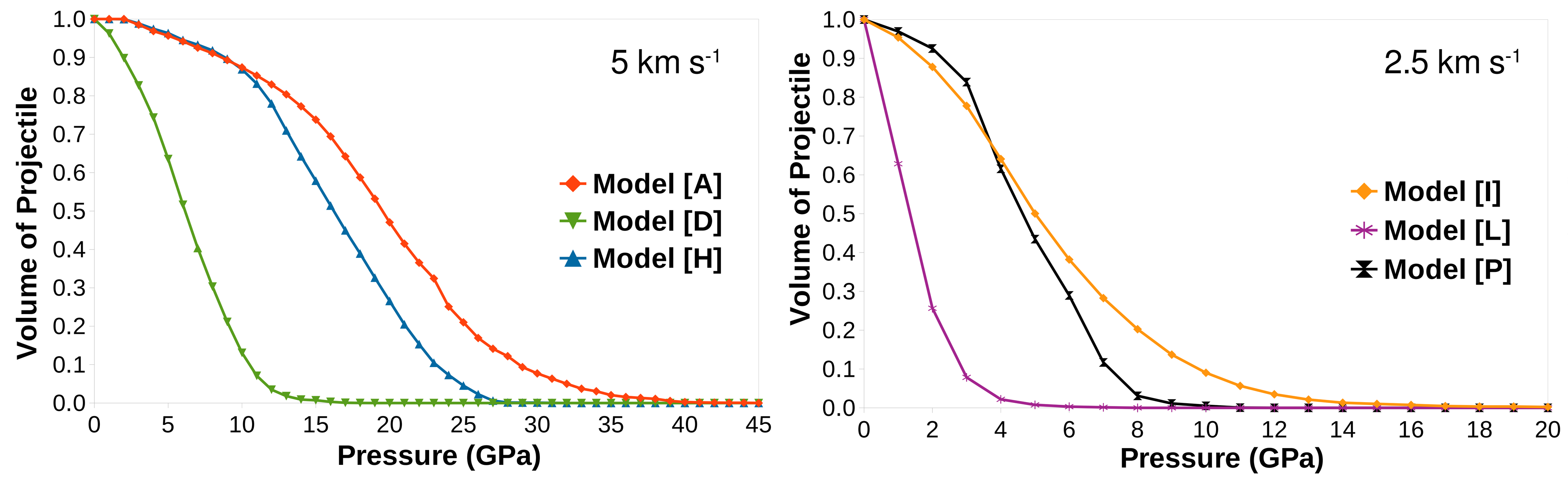


Figure 3a | Graphs showing peakP experienced by the projectile as a function of volume in 5 km s^{-1} (left) and 2.5 km s^{-1} (right) model runs.

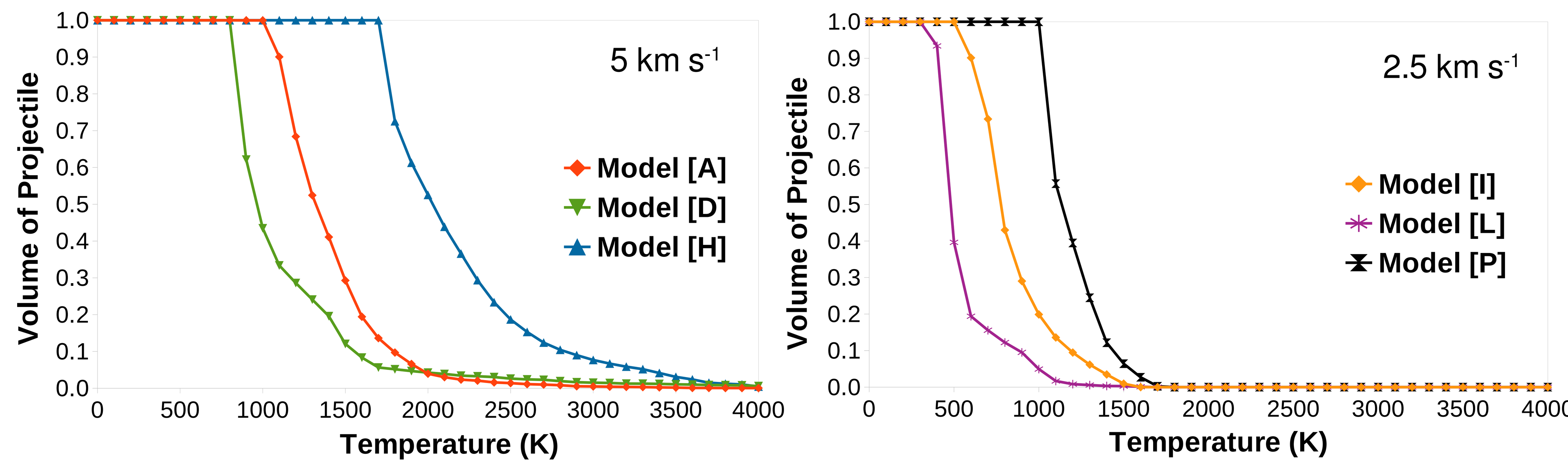


Figure 3b | Graphs showing peakT experienced by the projectile as a function of volume in 5 km s^{-1} (left) and 2.5 km s^{-1} (right) model runs.

References

[1] Armstrong, J. C. (2010) *Earth Moon Planets*, 107, 43–54. [2] Joy, K. H. et al. (2016) *Earth Moon Planets*, 118, 133-158. [3] Bellucci, J. J .et al. (2019) *Earth and Planetary Science Letters*, 510, 173-185. [4] Collins, G. S. et al. (2004) *MAPS*, 38, 217-231. [5] Amsden, A. et al. (1980) *LANL Report*, LA-8095. [6] Crawford, I. A. et al. (2008) *Astrobiology*, Vol: 8 (2), 242-252. [7] Burchell, M. J. et al. *Astrobiology* (2014) 14, 473-485. [8]. Parnell J. et al. (2010) *Meteoritics & Planetary Science*, 45, 1340-1358. [9] Mimura K. and Toyama S. (2004) *Geochimica et Cosmochimica Acta*, 69, 201-209. [10] Burchell M. J. et al. (2017) *Icarus*, 290, 81-88. [11] Kurosawa, K. and Genda, H. (2018) *Geophysical Research Letters*, 45, 620-626.

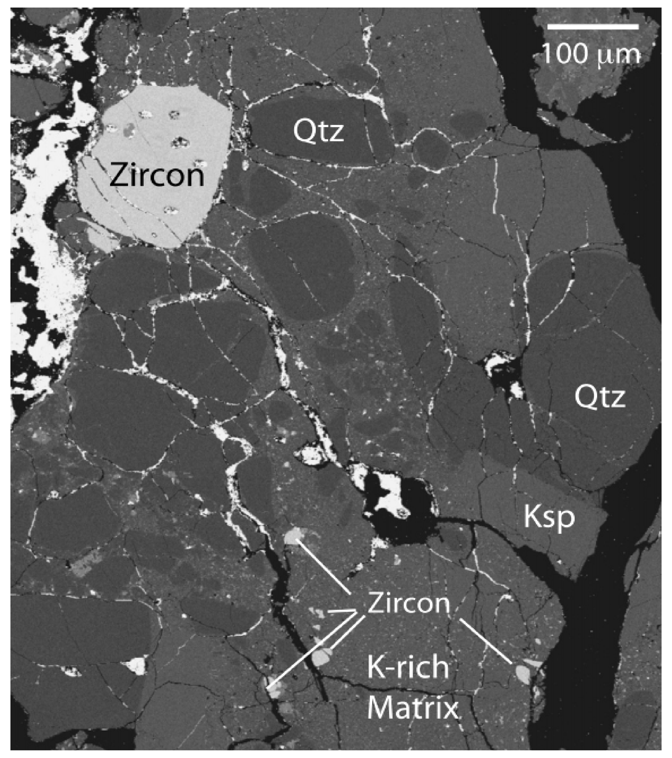
What survives?

Organic molecules		Survival pressure/ temperature	Reference
5 km s^{-1}	2.5 km s^{-1}		
Anthracene	Anthracene	15 GPa/700 K	[7]
Stearic acid	Stearic acid	15 GPa/650 K	
Dimethylsulfoxide (DMSO)	Dimethylsulfoxide (DMSO)	4 GPa	
N-alkanes; steranes;hopanes	N-alkanes; steranes;hopanes	30 Gpa/ 2500 K	[8]
PAHs	PAHs	30 GPa	[9]
Diatoms <30 µm	Diatoms <30 µm	19 GPa	[10]
Diatoms >100 µm	Diatoms >100 µm	2.3 GPa	

Table 2 | Green: likely to survive in all models, Orange: depends on model parameters, Red: likely destroyed in all models.

Conclusions

- **Table 2 shows the likelihood of survival** for some potential examples of organic materials in terrestrial meteorites.
- **Temperatures experienced by all of the projectiles are higher than expected** relative to their peak pressures.
- This is likely due to the **domination of shear heating compared to shock heating** experienced by the projectile during low-velocity impacts when rock strength is considered [11].
- Comparisons to work in [6] show that **we expect less survivability in models with 5 km s^{-1} projectile velocity** due to increased peakT.
- The most **favourable conditions** for survivability would be in a **solid projectile, impacting at low velocity into a highly porous target,** like that in Model L.



Terrestrial zircons

Could we have already found terrestrial material on the lunar surface? This sample from Apollo 14 **may be the first example of a terrestrial meteorite** and would be one of the oldest rocks ever found at ~4 billion years old.

Figure 4 | Possible terrestrial zircons shown in a backscatter electron image from an Apollo 14 sample. [3]

Acknowledgements

We gratefully acknowledge the developers of iSALE-2D and thank STFC for funding.

email: shalim03@mail.bbk.ac.uk