EPSC Abstracts
Vol. 9, EPSC2014-68, 2014
European Planetary Science Congress 2014

PANSPERMIA SURVIVAL SCENARIOS FOR ORGANISMS THAT SURVIVE TYPICAL HYPERVELOCITY SOLAR SYSTEM IMPACT EVENTS.

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Introduction:

Previous experimental studies have demonstrated the survivability of living cells during hypervelocity impact events, testing the panspermia and litho-panspermia hypotheses [1]. It has been demonstrated by the authors that Nannochloropsis Oculata Phytoplankton, a eukaryotic photosynthesizing autotroph found in the 'euphotic zone' (sunlit surface layers of oceans [2]), survive impacts up to 6.93 km s^{-1} (approx. shock pressure 40 GPa) [3, 4]. Also shown to survive impacts up to 5.49 km s^{-1} is the tardigrade species Hypsibius dujardini (a complex micro-animal consisting of 40,000 cells) [5, 6]. It has also been shown that they can survive sustained pressures up to 600 MPa using a water filled pressure capsule [7]. Additionally bacteria can survive impacts up to 5.4 km s^{-1} (~30 GPa) – albeit with a low probability of survival [1], and the survivability of yeast spores in impacts up to 7.4 km s^{-1} (~30 GPa) has also recently been demonstrated [8]. Other groups have also reported that the lichen Xanthoria elegans is able to survive shocks in similar pressure ranges (~40 GPa) [9]. Here we present various simulated impact regimes to show which scenarios are condusive to the panspermia hypothesis of the natural transfer of life (via an icy body) through space to an extraterrestrial environment.

Methodology:

Shock Pressure Experienced During Impact: A series of simulated impacts were run using Ansys' AUTODYN software using a 2-D Lagrangian mesh solver with axial symmetry. 37 pressure tracking gauges were placed throughout the projectile to record the pressures during the impact event (Fig. 1).

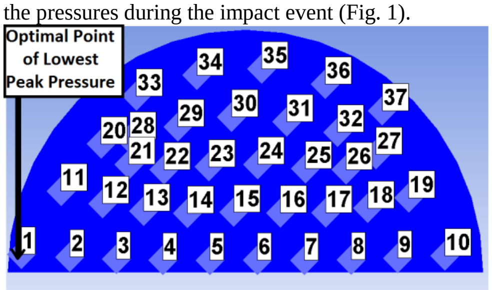

Fig. 1. Water ice impactor showing position of pressure tracking gauges. The impactor is travelling left to right onto a target on the extreme right.

The Optimal Point ('Op.P.') of lowest peak pressure during the impact was found to be gauge No. 1 in all instances. Thus, these pressure values are used for the 'best case' survival scenario (i.e. assuming significant numbers of an organism are distributed across the body such that survival depends only on the lowest peak pressure during impact). The simulations consist of an icy body impacting into an ocean and a rocky silicate body (Fig. 2). Float glass is used to simulate the silicate body, as work to validate a realistic basaltic analogue model is ongoing by the authors.

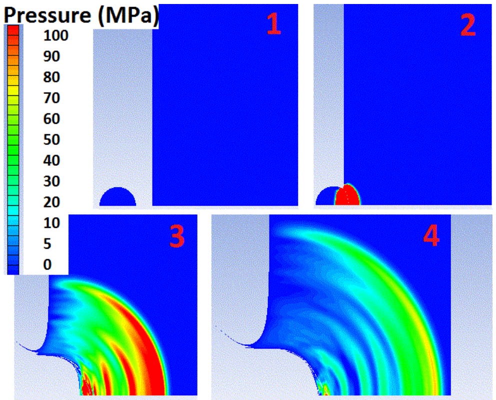

Fig. 2. Ansys AUTODYN simulation showing pressure contours for a 200 m water ice projectile impacting an ocean at 1.5 km s^{-1}. (Image timesteps - 0, 97, 390, & 560 ms into run).

Size & Pressure Independence: 23 different sized projectiles (R = 0.01 – 10,000 m) were simulated impacting a target ocean to confirm peak pressure does not depend on the size of the impactor (Fig. 3). The 23 different sized projectiles were also tested at 9 different impact velocities (0.25 – 5.0 km s^{-1}), each showing the same independence of size. All subsequent impact simulations used a 200 m diameter projectile.

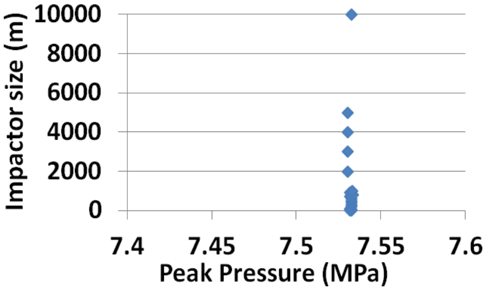

Fig. 3. Impactor size vs. peak pressure (0.25 km s^{-1} impacts) showing peak impact pressure is independent of size.

Results:

Impact Velocities: An optimum situation is assumed of a projectile passing near to a target body and being captured by the target body's own gravity well. Thus the impact velocity will be equal to the body's local escape velocity. Escape velocities for all bodies considered were calculated via Eq. 1:

$$v_{\mathrm{esc}} = \sqrt{\frac{2\,G\,M}{R}} \tag{Eq. 1}$$

where G is the gravitational constant, and M and R are the target body's mass (kg) and radius (m) respectively. Table 1 below shows a variety of target bodies and the different species that could survive impact onto them.

Table 1. Max. pressures and associated species survival for various impact environments (or bodies with equal V_{esc}.).

Target Body for Impact	*Escape Velocity (km s^{-1})*	*Pressure at Op.P. (Oceanic Impact) AUTODYN (MPa)*	*Species That Could Survive (Oceanic Impact)*	*Pressure at Op.P. (Rocky Impact) AUTODYN (MPa)*	*Species That Could Survive (Rocky Impact)*
Enceladus	0.25	7.5318	TBYLP	11.150	TBYLP
Ceres	0.51	17.248	TBYLP	34.203	TBYLP
Pluto	1.27	142.16	TBYLP	312.81	TBYLP
Europa	2.02	342.69	TBYLP	787.70	T*BYLP
The Moon	2.38	459.01	TBYLP	1113.2	BYLP
Titan	2.65	551.99	TBYLP	1368.0	BYLP
Mercury	4.25	1428.7	BYPL	3161.3	BYLP
Mars	5.02	2000.6	BYPL	4105.1	BYLP
Earth	11.2	9632.9	BYPL	15177	BYLP
*GJ 581d	19.5	23220	BYPL	N/A	N/A
†GJ 581d	22.0	N/A	N/A	63180	None
*GJ 581g	13.9	14557	BYPL	N/A	N/A
†GJ 581g	16.1	N/A	N/A	51041	None

* = if a water/ice composition, † = if a rocky composition. T= Tardigrade, B= Bacteria, Y= Yeast, P= Phytoplankton, & L= Lichen. T*= Possible T survival if population is large.

Survival Within The Solar System: The results presented here indicate the tardigrade species could only survive oceanic and rocky impacts up to 3, & 2 km s^{-1} respectively (Fig. 4 & 5). Thus, impact survival can occur on bodies such as Enceladus, Ceres (and all asteroids), Pluto (and equal or smaller Keiper Belt Objects), Europa, and any bodies similar to the Moon or Titan that have substantial liquid bodies on their surfaces. However, the other four organisms considered here show that impact survival can occur anywhere within the solar system with the exception only of the four outer solar system gas planets.

Extrasolar Planetary Impacts: Two Super-Earth exoplanets found to be orbiting within the habitable zone of their parent star (and thus have the potential for liquid water on their surfaces) are GJ 581d and GJ 581g. If homogeneous, and composed primarily of the perovskite phase of $MgSiO_3$ (Earth-like), the radii of GJ 581d and GJ 581g are expected to be 1.8 & 1.5 R_E respectively, or 2.3 & 2.0 R_E if water-ice [10,11], and all radii are predicted to be 20% smaller if the planet is differentiated [10]. However, survival is still possible on Super-Earths composed of water/ice beyond our solar system, but survival appears unattainable for rocky Super-Earths without an aid, such as atmospheric drag forces lowering the impactor's speed.

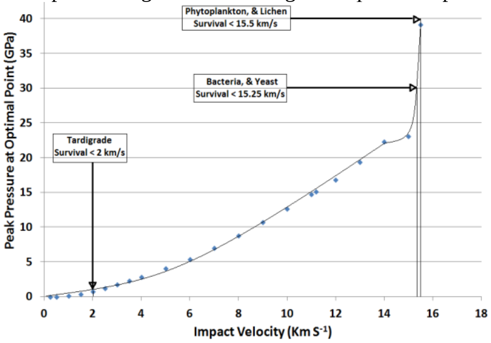

Fig. 4. Impact velocity vs. peak pressure at Op.P. for water ice projectile impacting rocky body.

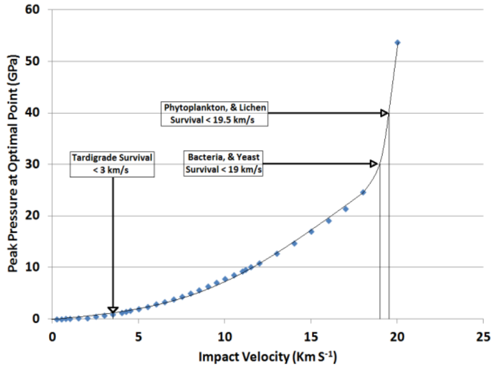

Fig. 5. Impact velocity vs. peak pressure at Op.P. for water ice projectile impacting water/icy body.

Conclusions:

The natural transfer of life throughout the solar system via impacts is possible for a variety of simple species. Some Super-Earths beyond our solar system are also within their survival tolerances. Oceanic impacts allow higher survival rates than rocky body impacts. However, atmospheres on bodies can lower an impactor's speed, increasing the probability of survival. Even the humble tardigrade (a complex life-form) could survive impacts onto small moons and asteroids.

References: **[1]** Burchell M. J. et. al. (2004). *MNRAS*, 352; 1273. **[2]** Ghosal S. et. al. (2002). *NASA/TM-2001-210935*, 88. **[3]** Pasini D. L. S. et al. *LPSC44*, 1497. (2013). **[4]** Pasini D. L. S. et. al. *EPSC2013*, 396. (2013). **[5]** Pasini D. L. S. et al. *LPSC45*, 1789. (2014). **[6]** Pasini D. L. S. et. al. *EPSC2014*, 67. (2014). **[7]** Seki K. et al. *Nature*, 395. 853-854. (1998). **[8]** Price M. C. et al. (2013). *Icarus, 222*, 263. **[9]** Horneck G., et al. (2008) *Astrobiology, 8*, 17. **[10]** Wordsworth R. et. al. *AJL 733*, L48. (2011). **[11]** Vogt S. et. al. arXiv:1009.5733v1. (2010).