SURVIVAL OF SEEDS IN IMPACTS AT 1 KM S^{-1} AND ABOVE. G. LeVoci[1], M. J. Burchell[1] and D. Tepfer[2], [1]School of Physical Science, Ingram Building, Univ. of Kent, Canterbury, Kent CT2 7NH, United Kingdom (M.J.Burchell@kent.ac.uk), [2] Biologie de al Rhizosphère, Institut National de la Recherche Agronomique, F-78026 Versailles, France.

Introduction: The survival of a variety of biological samples (bacteria and bacterial spores) in hypervelocity impacts has been established in recent years. That micro-organisms could survive in impacts at 5 km s^{-1} was shown initially [1], followed by survival at speeds up to 7 km s^{-1} [2]. This was for a variety of micro-organisms impacted on a range of target types using a two stage light gas gun. The microorganisms experienced shocks at pressures up to an estimated 78 GPa. In parallel, flyer plate experiments have shown that micro-organisms can survive shocks up to 50 GPa [3, 4]. In all cases the survival rate falls rapidly once pressures exceed a few GPa. These studies suggested that Panspermia (the natural transfer of life through space, see [5] for a recent review) could occur via the interplanetary transfer of bacteria, *e.g.* in the Martian meteorites found on Earth. Conversely, other authors have pointed out that ejecta from impacts on Earth may travel into space with various destinations. They could continue into space away from the Earth, They could re-enter the Earth's atmosphere and thus re-seed the Earth [6] or could strike the Moon in an impact which would occur at speeds in the range 2.3 - 5 km s^{-1} [7].

As an extension of this earlier work, recently, plant seeds (mounted in epoxy "rocks") were fired at speeds of 1-3 km s^{-1} into water [8]. No viable (able to germinate) seeds survived. However, large seed fragments were obtained after impact, suggesting that variation in the impact conditions might permit survival of whole seeds or that viable cells might survive within the fragments. Some of these conditions were investigated here.

Method: The seeds tested here were mounted in cubes of epoxy resin (as in [8]), simulating their being inside "rocks" (see Fig. 1 for an example). The idea would be that seeds fell into fractures in the rocks on a planetary surface. The rock was then ejected into space after a nearby large impact and makes its way to a second body which it then impacts.

The analogue "rocks" used here were about 1.5 mm along each side, and each typically contained 3 – 5 seeds, either Arabidopsis (1 shot) or mint (5 shots). Cress, alfalfa and tobacco were used previously in [8]. The mint seeds in the current work take longer to germinate under ideal conditions (e.g. mint requires ~14 days compared to the typically 1 – 2 days for the seeds used in [8]), but this was accepted as a deliberate attempt to experiment with a different range of seeds.

The "rocks" were fired in a two stage light gas gun [9] onto water targets in the same fashion as reported in [8]. We tested impact speeds of 1 and 3 km s^{-1} and impact angles of zero (normal incidence), 30 and 60 degrees (from normal incidence). By varying the impact angle, we should reduce the peak shock pressure P_o to $P_o cos\theta$, where normal incidence is taken as $\theta = 0°$ [10]. Peak shock pressures were calculated using the planar impact approximation, although an assumption had to be made for the relation between wave to particle speed for epoxy. For normal incidence, the peak shock pressures for impacts here at 1 and 3 km s^{-1} are roughly estimated as 0.5 and 1 GPa, respectively. It should also be noted that these peak pressures are only applicable to the leading part of the impactor, in the trailing part a lower pressure is experienced (perhaps only 25% of the peak value, see [7] for a discussion). After each shot, the water was filtered to look for projectile and seed fragments.

The Arabidopsis impact was at 1.06 km s^{-1} (all speeds are accurate to better than 1%) and 60º from normal incidence. The mint shots were at: 1.08 and 1.10 km s^{-1} (both normal incidence), 1.09 km s^{-1} (30º incidence), 1.02 km s^{-1} (60º incidence) and 3.17 km s^{-1} (30º incidence).

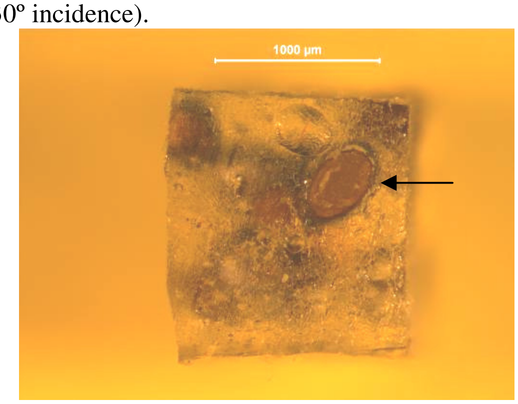

Fig. 1. Typical projectile before a shot. Dark seeds are visible in the epoxy cube. A seed near the surface is shown arrowed.

Results: With 2 exceptions, the results so far are similar to those obtained in [8]. Namely, significant fragments of the epoxy projectile can be found after impact (e.g. Fig. 2). At the lowest speed and shock pressures, these are fairly intact albeit with fractures, and as speed (or shock pressure increases) the epoxy is only found in broken form. Seed "fragments" can be obtained after impact from both the recovered sections of epoxy projectile and as loose items from the water. The seed "fragments" can range in size from up to 100% of the pre-impact seed size down to much smaller sizes (e.g. 20%, although the lower limit has not yet been firmly established). As impact speed (and shock pressure increase) the mean fragment size falls.

The major difference to the earlier work, lies in the results of the two shots of mint seeds at 1 km s^{-1}.and normal incidence. In both cases, what appear to be intact seeds have been recovered after impact. One of these seeds was placed in a nutrient gel to attempt germination. This germination method was tested successfully with both unshot seeds and with those extracted from unshot epoxy projectiles. In the case of the seed recovered after a shot, germination also occurred. The germinated seed is shown (after 2 weeks on the growth medium) in Fig. 3.

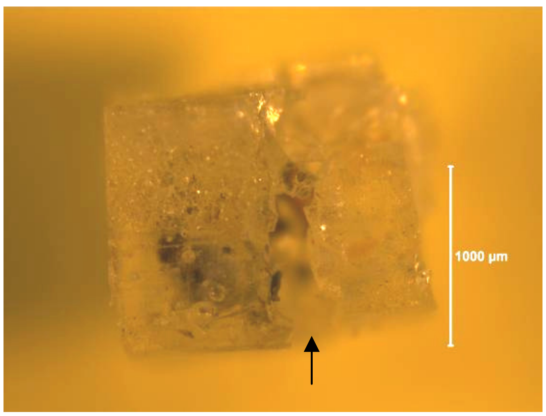

Fig. 2. Projectile after capture in water at 1.08 km s^{-1}. The epoxy has split (arrowed) and some seeds (or fragments thereof) have been liberated whilst others were retained.

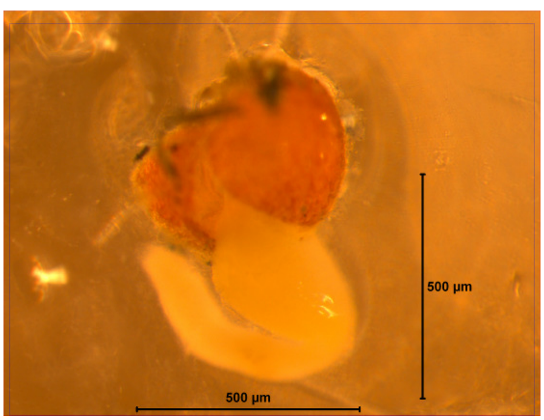

Fig. 3. Growth of a mint seed 2 weeks after recovery from the water target following a normal incidence impact at 1.08 km s^{-1}. The seed coating has split and the growth is emerging in the bottom half of the image.

Discussion: The germination of an imbedded seed after impact into water at 1 km s^{-1} encourages the hope that other survival events can be observed, even at higher impact speeds. Similar experiments with bacteria were carried out with large numbers of cells [1-2]. By contrast here, only a few seeds can be tested in a given experiment, reducing the recovery of survivors. Extrapolating to the numbers of bacteria tested in previous experiments would suggest seed survival at higher impact speeds. Seeds of different species are morphologically variable, and the structure of the seed coat is likely a factor in impact survival. Thus, many physical and biological variables remain to be tested.

Bacterial life was present on Earth 3.5 billion years ago, but seeds do not appear in the fossil record until the Devonian, about 0.5 bya. It therefore seems unlikely that seeds like those tested here could have carried life to Earth. It was nevertheless suggested that seeds are informative models for a Panspermia vehicle, and that even if a seed-like entity introduced into a sterile environment does not survive to germinate, it could release viable cells or microorganisms protected within [11], which could have jump started life on Earth.

In addition, the impact speed of 1 km s^{-1} at which seed survival was found here, is close to the minimum limit for impact speeds of Earth rocks onto the Moon. A natural lunar repository of fossil terrestrial seeds may not be impossible.

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