MARS METEORITES AND PANSPERMIAN POSSIBILITIES. H. J. Melosh, Lunar and Planetary Lab (University of Arizona, Tucson AZ 85721, jmelosh@lpl.arizona.edu).

It is now widely accepted that the SNC meteorite clan, including the rogue ALH 84001, originated on Mars. However, only two decades ago, no less an authority than Gene Shoemaker had confidently asserted that any material ejected from the surface of a planet at escape velocity would be either vaporized or completely melted: Certainly, any microorganisms residing in it would be destroyed by the heat. So what has changed in the meantime that now permits us to think that, not only may rocks be launched into space from another planet, but that these rocks might, just possibly, carry viable microorganisms from one planet to another?

The principal argument that impacts can eject nearly intact rocks into interplanetary space is derived from the rocks themselves: In the wake of much argument and measurement, a convincing case has been built that the SNC meteorite clan, in particular the gas-containing EETA 79001, originated on the planet Mars. The case for meteorite ejection of intact rocks from a planetary-scale body was further bolstered by the recognition of meteorites from the moon in 1983. Although some of these rocks show signs of high shock pressures (Shergotty, the type Shergottite, contains the first diaplectic glass--Maskelyenite--recognized by terrestrial mineralogists) others, such as Nakhla, exhibit no trace of shock metamorphism.

These observations are now supported by both theoretical understanding of how lightly-shocked planetary surface material can be launched at high speed by large impacts as well as by laboratory experiments that demonstrate that the process works as expected. The most characteristic feature of this process is that the high-speed lightly-shocked ejecta <u>must</u> originate from close to the surface of the target planet.

The old (and still mostly correct) argument against the possibility of high-speed ejection of intact rocks revolves around the Hugoniot relation that connects the pressure jump across a shock wave with the corresponding velocity jump. This relation has been measured directly for a wide variety of geologic materials and in general shows that, if the velocity jump is comparable to the escape velocity of Mars (5.0 km/sec), then the pressure jump must exceed about 150 GPa for basalt--easily enough to melt and partly vaporize the rock.

However, although the Hugoniot relation holds for the bulk of the rocks in the vicinity of a large impact, a small volume very close to the surface can escape its constraints. At a free surface the pressure must stay rigorously at zero, no matter how close to the impact site the surface rocks may lie. Thus, surface rocks very close to the site where the impactor strikes (which is generally well inside the final crater) remain at zero pressure while other rocks a short distance below the surface are compressed to high pressure by the impact. This produces a large pressure gradient in the rocks just below the surface. Since the acceleration of this material is directly proportional to the pressure gradient, these rocks, protected from high pressure by their proximity to the free surface, achieve high velocities without being subjected to high pressures [1, 2].

This theoretical picture was augmented by an experiment performed by Andy Gratz, Bill Nellis and Niel Hinsey at the Lawrence-Livermore National Laboratory in 1993 [3]. In this experiment the ejecta from the face of a block of Westerly Granite that had been impacted at 4 km/sec with a penny-sized aluminum disk was collected. The result confirmed theoretical expectations: mm size fragments of unshocked quartz were blasted out at speeds of more than 1 km/sec, a substantial fraction of the impact speed itself.

The case for high-speed ejection of lightly shocked material is also supported by observations of the ejecta of Ries Crater in Germany. In addition to the usual highly-shocked and melted debris (for example, the Moldavite tektites were produced from melted target rocks and showered over the terrain that would become Czechoslovakia) lightly-shocked blocks of Malm limestone, the uppermost geologic rock unit at the site of the impact, were ejected at least 200 km from the impact site at a speed of more than 1.4 km/sec. Although these blocks did not actually leave the earth, their ejection speed is far higher than the Hugoniot relation would predict from their observed shock damage.

It is thus clear that at least some of the ejecta from a large meteorite impact is both lightly-shocked and swift, some if it capable of leaving the planet it originated on. Moreover, this material comes from close to the planet's surface. Since this is just where biological, specifically microbial, activity is most intense, it seems possible that some of this ejecta may carry microorganisms into space.

It is easy to establish some limits on the maximum shock pressure that a rock carrying viable microorganisms might endure. At relatively low shock pressures P the main effect of the shock wave is to crush the rock, eliminating any initial porosity f that may be present. The irreversible work done on the rock as it is crushed is Pf. It seems likely that if this work raises the rock's temperature much above 100° C it will be sterilized: no viable microorganisms will survive. The shock pressure P that can just raise the temperature of a typical rock with density 2700 kg/m^3 and heat capacity 700 J/kg-K from 0 to 100°C is about 1 GPa. This pressure corresponds approximately with the Hugoniot Elastic Limit of typical rocks, a pressure where substantial crushing is noted experimentally and where shatter cones may appear.

Given this limit on the maximum pressure which a rock may experience without being sterilized (I will call such unsterilized ejecta "fecund" material in the following discussion), it is possible to estimate the total mass and fragment size of ejecta from Mars (or the Earth!) which may achieve escape velocity and could potentially transport life from one planet to another. This estimate shows that impacts that produce craters more than about 30 km in diameter are capable of ejecting large numbers of fecund fragments larger than 1 m in diameter [4].

Upon reaching space many microorganisms entrained in the ejecta will die. However, the combination of freeze-drying in hard vacuum (lopholization) and the preservation of microbial spores may make it possible for an ejecta fragment to inoculate any other world it falls on with a sample of life from its planet of origin. The large size of many ejecta fragments (1 m or more in diameter) can easily shield its microbial passengers from UV radiation, although shielding from cosmic rays would require a much larger fragment (10 m or more in diameter). One unanswered question is just how much radiation various microorganisms can tolerate in a dormant state: The many measurements of the radiation tolerance of metabolizing organisms are not relevant here, because such organisms have active systems that repair radiation damage to their DNA.

Upon arrival at a new plant, the few-m size of such fragments is nearly ideal for deceleration in the atmosphere of one of the terrestrial planets (Early Mars would have been more favorable for this scenario than the present planet) and arrival at the surface at relatively low velocity (near terminal velocity for the atmosphere). Such a rock would have experienced crushing aerodynamic forces during its deceleration and the former interior would thus be exposed: a better vector for inoculating planets with life probably could not have been designed intentionally.

Recent work by Gladman et al. [5] has suggested that the transfer of ejecta from Mars to Earth is assisted by a "fast track" through a series of orbital resonances that cuts the expected transfer time of ejecta from more than 10 Myr (estimated from Monte Carlo orbital evolution models) to the order of 1 Myr. Earth to Mars evolution is generally slower and more difficult, so a smaller proportion of Earth ejecta hit Mars than Mars ejecta hit Earth, although both processes do take place. Similarly, much ejecta finds its way to Venus as well.

It thus seems plausible that a significant amount of exchange of ejecta between the terrestrial planets has occurred, especially during the era of heavy bombardment when cratering rates were at least 1000 times higher than at present. Recent discoveries of ancient fossils on Earth suggest that life was extant here, at least, during this era, so a very real possibility exists that Early Mars and Venus had the possibility of being colonized by terrestrial life (or perhaps life originated on Mars or Venus and terrestrial life is its offspring!). The proof of this proposal would be the discovery of life (either extant or fossil) that showed affinities with terrestrial life.

References: [1] Melosh, H.J. (1984)*Icarus* **59**, 234. [2] Melosh, H.J. (1985)*Geology* **13**, 144. [3] Gratz, A.J., Nellis, W.J. & Hinsey, N.A. (1993)*Nature* **363**, 522. [4] Melosh, H.J. (1988)*Nature* **332**, 687. [5] Gladman, B.J., Burns, J.A., Duncan, M., Lee, P. & Levinson, H.F. (1996)*Science* **271**, 1387.