PRODUCTION, ACCELERATION AND DISTRIBUTION OF MICROTEKTITES ON EARTH, MARS, VENUS AND TITAN R. D. Lorenz, Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721-0092, USA (rlorenz@lpl.arizona.edu)

Introduction: Microtektites, formed by melt disruption and condensation of rock vapor in the expanding impact fireball can only be distributed widely by events energetic enough to punch through the atmosphere and distribute ejecta on ballistic trajectories. I compare the formation and distribution environment for microtektites on Mars, Venus and Titan with that of Earth. Typical impact velocity, gravity and atmospheric parameters are all controlling factors. Mars' thin atmosphere means that this process can occur for smaller, and therefore more frequent, impact events [1].

Atmosphere-Piercing Impacts: Part of the energy of an impact event is deposited in a fireball of gas, whose volume relates to the energy [2]. This fireball will expand, nominally to a size at which its pressure will have fallen to the ambient surface pressure of the planet and any material in it ('fallout') is deposited around, or in a streak downwind of, the source crater. However, if the fireball is energetic enough that its diameter is comparable to an atmospheric scale height, it keeps expanding upwards, accelerating entrained material into space. This 'blowout' has been observed in a high-altitude nuclear test ('Teak', 3.8MT) as well as in the SL-9 impact plumes on Jupiter. The phenomenon is also responsible for the distribution of of microtektites on Earth (which are dispersed far too widely to have transported within the atmosphere) and is also believed to lead to the formation of the parabolic features around impact craters on Venus [3] – in these features the ejecta is dispersed with a circular symmetry by ballistic transport above the atmosphere, and then the material is winnowed by East-West winds in Venus' thick atmosphere.

On Earth, an event needs to be energetic enough to form a 10km crater to pierce the atmosphere (e.g. the Ivory Coast microtektite field is associated with the 12km Bosumtwi crater). In Mars' thin atmosphere, the corresponding threshold size is only about 2.5 km, thus atmosphere-piercing events are relatively common on Mars, while less so on Venus and Titan, with thicker atmospheres. The volume of material available for tektites and microtektites is limited by the melt and melt+vapor fraction of material produced by the impact – this depends somewhat on impact velocity as well as the crater size [4] : the fine ejecta volume for terrestrial craters appears to be around $5 \times 10^{-5} D_c^{3.84}$, where , where D_c is the crater diameter.

Global Ejecta Transport: On Earth, a velocity of around 10 km/s is needed to transport material half-way around the planet. Mars is both smaller in diameter, and has a lower gravity, so the corresponding speeds are lower. Trajectory simulations (fig.1) show that particle trajectories are appreciably affected by planetary rotation, and only 4.5 km/s is needed to carry particles half-way around the planet. On Earth, microtektites are distributed with a surface number density (or equivalently, a layer thickness t) that varies with crater radius R_c and distance d as $t = kR_c^x (R_c/d)^n$, with x=0.74, n=3 and k=0.14 For Bosumtwi [5], there are around 100 particles (100μm or larger) per square cm, at a distance of about 2000km.

Since dispersal velocities are typically ~1/2 of the impact velocity, and the altitude at which atmospheric density becomes negligible (~10^{-10} kgm^{-3}) is about the same for Venus as for Earth, the dispersal kinematics are similar. For Mars, the impact velocities are about half of those typical for Earth, commensurate with the global transport velocities above, so again (fortuitously) the same relations may hold.

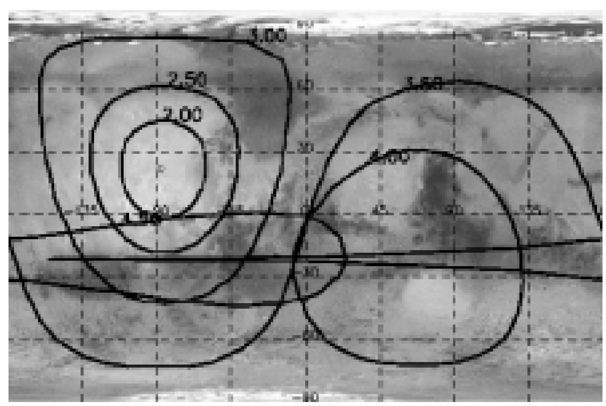

fig.1 Map of the Martian surface : diamond indicates example crater (Fesenkov, 86km dia – same lat/long as Chicxulub on Earth) contours (launch velocity km/s) show regions reached by particles launched at 45º. The poles are reached with about 3 km/s, and antipodes with 4.5 km/s. Note lateral displacement of contours, an dstretched tadpole shape of 4.5km/s contour, due to planetary rotation.

Spherules and Heating: Material melted in or condensing from the vapor plume of an impact will tend to condense as small spheres whose size is limited by surface tension's ability to overcome aerodynamic stress [6] and the spherules can be deposited as thick, uniform beds. More energetic events (higher velocity impact) produce smaller spheres : for Mars, with lower escape velocity and further from the sun, such velocities are lower than for Earth, and so spherules are larger. For the 2.5km crater event discussed above, the corresponding particle diameter would be 300 μm [1]. These and smaller particles, having condensed from melt or vapor, will have a molten texture.

Micrometeoroids, if large enough, can melt. But while for the Earth the temperatures experienced as a function of size and entry velocity [7] are such that cosmic spherules (i.e. melted micrometeoroids) of the same size as microtektites would appear melted, on Mars most meteoroids of that size would not due to the lower entry velocity, so a molten texture on a 300 micron (or smaller) particle on Mars discriminates against most micrometeorites and points to an impact crater origin [1].

Future Prospects for Space Missions:

Venus – distant plans only for balloon and/or sample return missions.

Mars - the present 2001 Mars lander is equipped (as was the ill-fated Mars Polar Lander) with a sampling arm, and a robotic arm camera with the ability to image the soil with ~20 μm pixels. With such a resolution, it should be possible to recognize 300 μm diameter particles as spherical and uniform, and with appropriate lighting a glassy texture might be apparent – this instrument may therefore be able to find preserved microtektite deposits. Analysis of returned samples in the next decade is likely to yield further insights.

Titan – RADAR imaging by Cassini in 2004-2008 may reveal ejecta deposits, and allow texture/thickness to be determined, as for Venus with Magellan, but Cassini will also have near-IR imaging, perhaps allowing particle sizes to be constrained.

Summary: Comparisons with Earth

Venus: high P, so only large impacts are atmosphere-piercing. High T and Vimp give ~2x larger melt+vapor fraction. Zonal winds cause near-field ejecta to be swept into parabolae. Planetary radius, vertical extent of atmosphere and gravity are same as earth, Vimp only modestly larger, so t vs d relationships for Earth still hold.

Moon : very low P so melt/vapor droplets distributed ballistically on essentially all impacts. But Vimp>>Vesc, so large fraction of ejecta escapes. Ejecta that is retained itself impacts surface at high speed.

Mars : low P, so even small impacts make microtektites. Vimp~ 50% of Earth, but gravity and planetary radius are also lower by a similar factor, so t vs d relationships for Earth probably still applicable.

Titan : moderate P. Similar atmospheric rotation to Venus, but atmosphere very vertically extended, so parabolae impossible – only eejecta streaks. Icy surface rather than rock, so melt production different : Vimp is poorly constrained, t vs d likely to be different.

Areas for Future Work

This abstract has qualitatively discussed the planetary settings for microtektite dispersal. The next step is a detailed, and probably numerical, investigation of the interaction of the fireball, its entrained particles, and the atmosphere. Size/distance relationships (which the terrestrial community could usefully document) may help constrain these processes.

References:

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