SHATTER CONES: TENSIONAL FRACTURING DIRECTED BY PROPAGATING RELEASE WAVE.

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Introduction: Shatter cones are regarded as only macroscopic indicators of shock-metamorphism [1]. Dietz suggested that shatter cones could be used as an evidence for hypervelocity impacts in 1947 [2]. Although shatter cones are widely recognized as impact-indicators, how they form is not well understood [1, 3].

Two explanations for shatter cones have been widely sited in recent literature [3]. Those are hypothesis by Sagy et al. [4, 5] and by Baratoux and Melosh [6]. There are more recent ideas by Dawson [7] and by Kenkmann and Wilk [8].

Here shatter cones are explained as tensional fracturing directed by propagating release wave during excavation stage of impact cratering.

Explanation: It has been noted that shatter cone surfaces resemble tensional fracture features called plumose structure for a long time. Model suggested by Sagy et al. is relying on this similarity. Kenkmann and Wilk describe striation details of shatter cone surfaces and those apply for plumose structure striation very well.

In tectonic settings plumose structures caused by tensional stress can be seen in countless outcrops around the World. These fractures are almost planar surfaces with shallow topography. Often they are striated but not always. Fractures caused by tensional stress in static stress environment propagate from origin at subsonic speed and perpendicular to direction of tensional stress.

During the impact event tensional stress is caused by the release wave from free surfaces into the shocked material [1, 9]. The release wave is propagating through shock wave pressurized target rock at supersonic speed and faster than the shock wave itself.

Tensional stress caused by the release wave is strongest at the release wave front, where fastest depressurizing of target rocks occurs. Release of pressure produces tensional stress which direction is parallel to the normal of the release wave front. Its direction is often almost the same as the direction of the normal of the shock front. That explain why shatter cones seem to point shock wave direction.

Strong tensional stress will burst open most exist fractures and pores in the rock. Some of which the shock front closed earlier. Tensional stress will also fracture weak points or other heterogeneities in target rock. All fracturing does not happen when tensional stress is strongest; fracturing can happen until target rock is depressurized.

All fractures opened by the release wave may act as origin of a shatter cone. But not in cases where fracture is not directed by moving release wave. Then it will produce a planar fracture.

In case of shatter cones, a fracture will not expand along a planar plane. When the front of the fracture advances, locus of the tensional stress is moving forward. Result is that the fracture will be directed to follow the propagating release wave. The fracture soon become inclined to direction of normal of the release wave front.

Straight fracture as fracture origin can explain planar shatter cone surfaces and may explain observed relations between shatter cones and multi joint surfaces. Shape of fracture origin will cause fracture to open asymmetrically. This explains why shatter cones have usually so many other shapes than ideal cones. For example curved fracture as origin may produce normal curved shatter cone surfaces when fracture open outward, but hourglass shaped shatter cone surface if fracture opens inward. Later may explain why some shatter cones are pointing opposite direction than others.

Sometimes shatter cone surfaces ends abruptly inside a healthy looking rock. These samples suggest that shatter cone formation does not need shearing like model by Dawson suggests. The fracture stops when the release wave escapes from it and tensional stress become too low. The fracture does not propagate as fast as the supersonic release wave.

Propagating fracture may also produce nesting fractures, which will produce nesting shatter cones. These nesting fractures may be caused by front wave as suggested by Sagy et al.

Striation or grooves of shatter cone surfaces are produced similar way than striation on plumose structures in tectonic environment as Sagy et al. suggested. Points on starting fracture front that are propagating fastest will start higher ridges or grooves on shatter cone surface. The more fracture is inclined to tensional stress direction, the more it will deepen shatter cone surface relief.

When fracture expands in different velocity in parallel and perpendicular to the direction of release wave, it will cause shatter cones to curve and spread in the end. When release wave depressurize rock its tail will slow down and this can also cause shatter cone curve in the end. Kenkmann and Wilk suggest that also bifurcation of striation may cause shatter cones to spread.

Simulations made by Baratoux and Melosh produces similar spreading cones with interfering waves.

According to explanation presented here, best-formed conical shatter cones may be started from tiny round voids in homogenous rock type. This can explain why nice conical shatter cones are rare, but more common in fine-grained sedimentary and volcanic rocks than in coarse-grained rocks.

Shatter cones seem to form prior and during final fragmentation of the target rock inside the crater. This explains why shatter cones can be found in breccia boulders ejected out from the crater, in clasts of suevite and in fractured bedrock below the crater floor.

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