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SHATTER CONES: DIAGNOSTIC IMPACT SIGNATURES

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Uniquely fractured target rocks known as shatter cones are associated with more than one half the world's 120 or so presently known impact structures. These are conical rock fragments which range from several millimeters to a few meters in length and whose surfaces are embossed with longitudal arrays of splayed "horsetail" packets of ridges and grooves. Shatter cones are a form of *tensile* rock failure in which a positive conical plug separates from a negative outer cup or mold and delicate ornaments radiating from an apex are preserved on surfaces of both portions. In contrast, *pressure* failures yield wall sliding accompanied by burnished surfaces of parallel (rather than diverging) grooves and masses of pulverized rock. Optical and scanning electron microscope studies of shatter coned rocks often show dense networks of open fractures. Microspherules within these fissures are interpreted as melt droplets of projectile and/or host material preserved in dilated target rock (1,2). The initial pressure pulse which is propagated from an impact or explosion event is followed immediately by a powerful tensional wave; strong residual tensile forces have been measured or implied in samples of artificially shocked materials (3,4).

Although distinct, shatter cones are sometimes confused with other striated geologic features such as ventifacts, stylolites, cone-in-cone, slickensides, and artificial blast plumes. Ventifacts are surface features only and are not fissures which permeate or penetrate host rocks. Stylolites are sheet-like veins of mineral concentrates whose compositions differ markedly from parent rocks. Cone-in-cone structures are compaction features which occur in coaxially stacked arrays, rather than shoulder-on-shoulder, and which commonly possess annular, rather than longitudinal, surface striations. Slickensides are parallel sets of mirror image, polished grooves and ridges rather than delicate diverging patterns. Blast plumes, such as those produced by quarrying operations, differ from shatter cones by displaying longitudal sharp ridges and rounded grooves on positive (convex) conical surfaces. In contrast, positive shatter cone faces display rounded ridges separated by sharp grooves - or the reverse on negative mold faces.

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Complete cones or solitary cones are rare, occurrences are usually as swarms in thoroughly fractured rock. Cone apices sometimes possess a clast or pebble of material inhomogeneous with host rock or often display a cavity indicating former presence of such material. Apical angles range from 60° to more than 120° but average around 90°. Cone flanks may flare or constrict to form trumpet or ogive shapes. Host rocks of similar lithology and distance from the center of an impact structure display shatter coning of similar apical angle, length, and axial orientation; variation seems controlled by target strength and shock wave peak value. Where orientation studies have been made and strata returned to pre-impact positions, cone apices point inward and upward toward ground zero. At smaller impact structures in the few kilometers diameter range (Steinheim, Decaturville) shatter coning develops near the center whereas at large sites (Sudbury, Vredefort), they develop in an outer ring of rock. Shatter cones develop best in brittle rocks subjected to shock pressures of about 10-200 Kilobars, outside most target zones of shock melting and formation of shock lamellae.

Shatter cones may form in a zone where an expanding shock wave propagating through a target decays to form an elastic wave. Near this transition zone, the expanding primary wave may strike a pebble or other inhomogeneity whose contrasting trasmission properties produce a scattered secondary wave. Interference between primary and secondary scattered waves produce conical stress fields with axes perpendicular to the plane of an advancing shock front. This model supports mechanisms capable of producing such shatter cone properties as orientation, apical clasts, lithic dependence, and shock pressure zonation. Although formational mechanics are still poorly understood, shatter cones have become the simplest geologic field criterion for recognizing astroblemes (ancient terrestrial impact structures).

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