The Physicalities of Hertzian Fractures

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ABSTRACT

In this Hertzian fracture study 5mm thick soda-lime glass plates were impacted by 5 mm steel projectiles with velocities of ~30 to ~91 m/s at angles between 45º and 60º -- 0/360º being vertical. Results were recorded photographically for comparison. Varied and diverse results were obtained beyond standard Hertzian fracture nomenclature, i.e., the crater, mirror, mist, hackle and Wallner line norm. Characteristics were logged and if necessary denotative titles were assigned. Multiple unnamed physicalities were discerned and are listed in fifteen main physical categories.

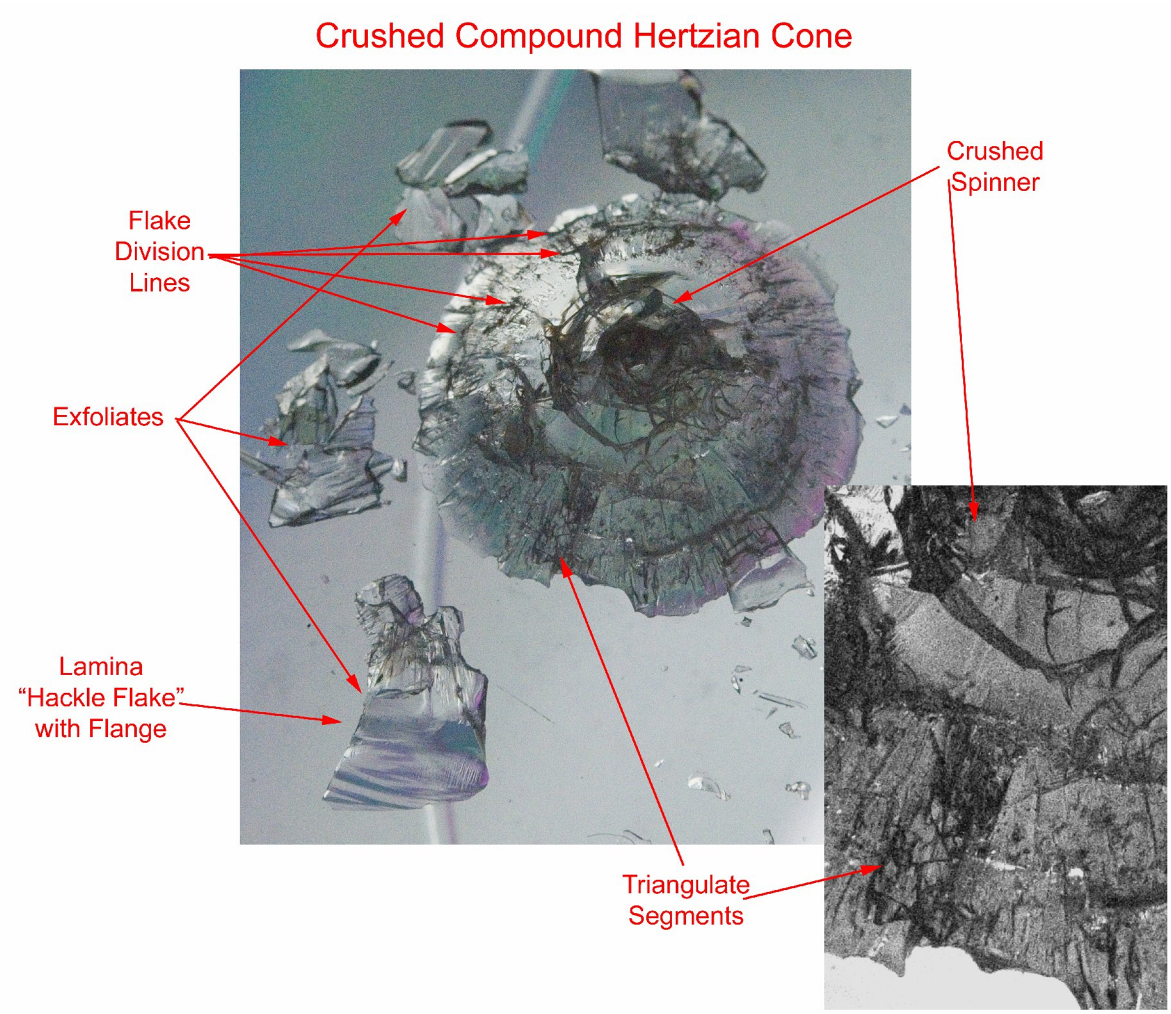

Figure 1 *A crushed Hertzian cone displays multiple aspects not covered by current facetal features; crater, mirror, mist, hackle and Wallner lines.*

Introduction

For millennia Hertzian fractures have been a bane and a blessing for mankind -- a partner and a pest. Flint knapping, the creation of Hertzian (conchoidal) fractures was integral to the survival and evolution of early mankind. The sharp, scalloped edges of stone provided weapons and tools for killing animals, preparing their flesh, bone and hides for the survival of the human race.[1]

They annoy drivers when wayward pebbles skip down a highway to ding and damage countless automobile windshields world wide. Conversely, they create a multi-billion-dollar world-wide industry in windshield repair and replacement. The same is true for the glass doors and windows of spacecraft, aircraft, homes and businesses.[2]

They facilitate drilling, for water, oil and natural gas by forming at the points of drill bit teeth, hundreds and thousands of feet below the Earth's surface.[3] But, they fracture teeth and dentures during a bite of the wrong candy bar or the mechanical teeth of a machine gear when hard items, much smaller than a monkey wrench, come between them.[4]

In forensics they are studied for bullet caliber and direction of fire and inform those who know them of the direction and speed of the impactor -- the faster the projectile, the narrower the cone.[5]

Still, nomenclature for Hertzian fractures is limited, or at least to some disciplines and fields. Differing fields use differing terms. Archaeologists refer to them as conchoidal fractures. Those who study projectile impacts in rock call them spall. Windshield repair folks call them dings. All have the same five features; point of impact or crater, mirror, mist, hackle and Wallner lines.

Fairly simple.

[1] *The World's Oldest Stone Artifacts from Gona, Ethiopia: Their Implications for Understanding Stone Technology and Patterns of Human Evolution Between 2·6–1·5 Million Years Ago*, Sileshi Semaw, Journal of Archaeological Science (2000) 27, 1197–1214

[2] Campfield, R., Ultra Bond, Inc., *Facts and Findings about Windshields*, the Insurance Journal, May 1, 2003, http://www.insurancejournal.com/services/newswire/2003/05/01/41550.htm

[3] *Fracture of Rock.* Chapter 6. M.H. Aliabadi. Computational Mechanics Publications. 1998. pp. 167-203.

[4] *Stress distribution and failure mode of dental ceramic structures under Hertzian indentation*, X.D. Dong, B.W. Darvell. Dental Materials Science, Faculty of Dentistry, The University of Hong Kong, Prince Philip Dental Hospital, Hong Kong, People's Republic of China, 2002.

[5] *The Morphology of Hertzian Cone in Plate Glass by Projectile Impact,* Miyamoto, A., Murakami, Y., The Society of Materials Science, Japan, Vol. 49, No.8, pp867-872, Aug. 2000

Methods

For studies below 45 m/s a standard steel yoke and arm support sling was used. In studies between 45 to 91 m/s samples were created with a conventional air rifle.[6] Velocity was adjusted by distance from the target, 7.62cm to 121cm. Both release systems were hand held to allow for rotational variances in steel ball projectiles. Sling samples were found to be primarily on Y axis rotation while air rifle samples exhibited multi-rotational impact evidence. Two to three layers of glass were used to allow confined fractures for viewing of samples from the base. Angles varied from 45º to 60º from true vertical at 0/360º.

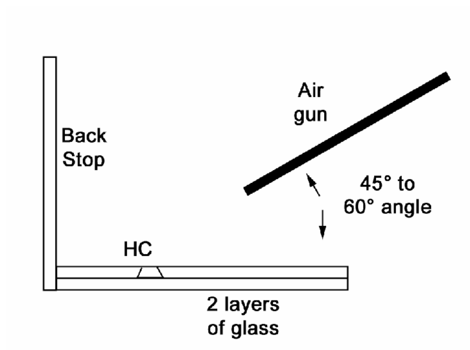

Figure 2 *Configuration of impact sample set.*

Common Terms

In practicality Hertzian fracture segments are much more detailed and divided than current diagrams. Here various features have been sub-divided into additional classifications with their own sets of segments. (Figure 9)

The three main segments are:

1. The cone – the solid or fragmented "plug" that is often pushed out during impact and is considered the positive segment.
2. The mold – the void in the overburden or glass plane after the cone is created. It is often referred to as "the fracture". In some fields it is the negative segment and can form as a mold for forming positive specimens of the cone by pushing clay or soft material into the empty area.
3. The fracture – the space between the cone and mold. It is neutral and is the void, the space between the former two segments. Often the cone and mold do not completely separate.

[6] An official 50-year commemorative Red Ryder carbine-action two-hundred-shot range model air rifle.

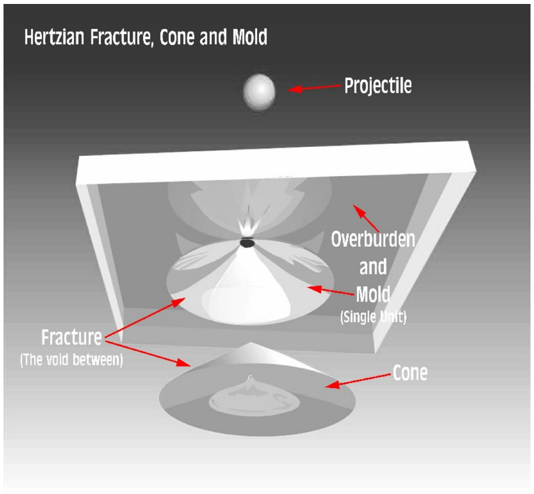

Figure 3 *Diagram of the three main segments of a simple Hertzian fracture in a glass plate; overburden and mold, fracture and cone.*

Neoteric Terms

Below is a list of Hertzian cone styles for comparison divided into differing segmental characteristics.

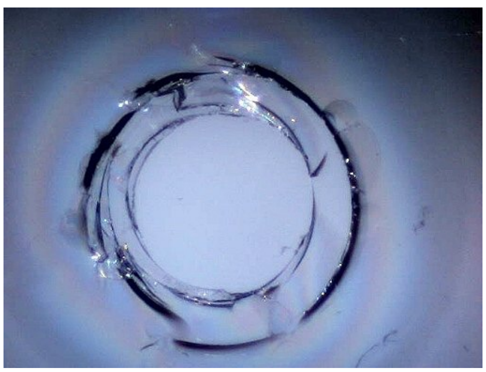

Figure 4 *Crater floor with rim fracture.*

I. Crater only. (figure 4)
Segments:
1. Crater floor with rim fracture.
Technically not a Hertzian cone fracture, but is a precursor to their formation at higher velocities. It is a simple circular fracture where the projectile impacted with surface.
2. Crater with floor rim and crater wall.

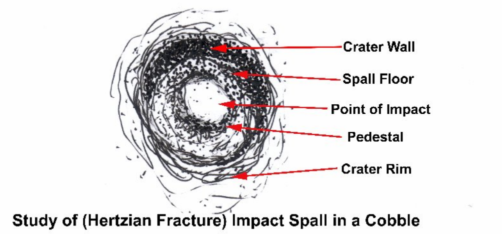

Figure 5 *Study of a spall crater as found in cobbles showing pedestal and point of impact. Hertzian fractures on spheroid targets often spall outward around the point of impact. These features are also seen in ballistic studies of projectiles into metal surfaces.*

II. Crater spall and pedestal. (figure 5)
Segments:
1. Crater floor.
2. Crater wall.
3. Rim fractures.
4. Possibility for radial cracks.[7]

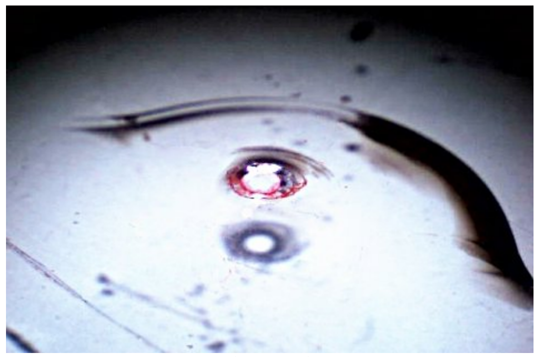

Figure 6 *A semi-cone with stained crater.*

III. Crater and semi-cone fracture. (figure 6)
Segments:
1. Crater floor.
2. Crater wall.
3. Rim fractures.
4. Possibility for feather hackles.
5. Semi-cone, usually created opposite the path of the projectile. However, extensive spin on a projectile can alter the location of the semi-cone.
6. The formation of Wallner lines is possible.
7. Possibility for radial cracks.
8. Possibility for multiple mirrors, mist areas and rings of hackles.

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[7] *Shock deformation in Triassic Buntsandstein conglomerates, Spain,* Ernstson Claudin Impact Structures – Meteorite Craters, Research on impact geology, geophysics, petrology, and impact cratering, Kord Ernstson, Ferran Claudin*, (2012)* http://www.impact-structures.com/2012/07/impact-induced-surface-hardening-of-polished-quartzite-cobbles-triassic-buntsandstein-conglomerates-northern-spain/

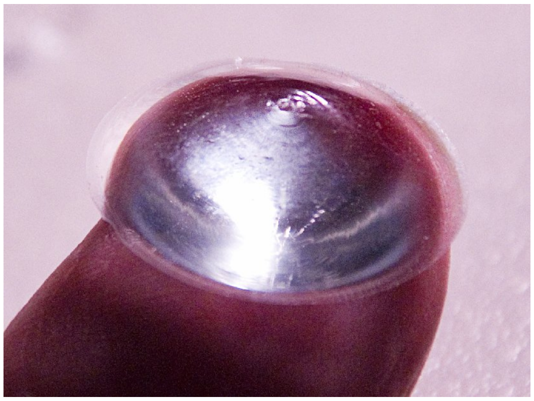

Figure 7 *A simple dome-shaped cone without overburden on a fingertip. The pedestal is truncated and remained attached to the overburden and mold.*

IV. Simple dome fracture and cone in overburden. (figure 7)

Segments:

4. Crater floor.
5. Crater wall.
6. Rim fractures.
7. Possibility for pedestal with tension (crab or braided) cracks.
8. Possibility for feather hackles.
9. Full cone, totality contained in the mirror.
10. The formation of Wallner lines is probable.
11. Possibility for radial cracks.

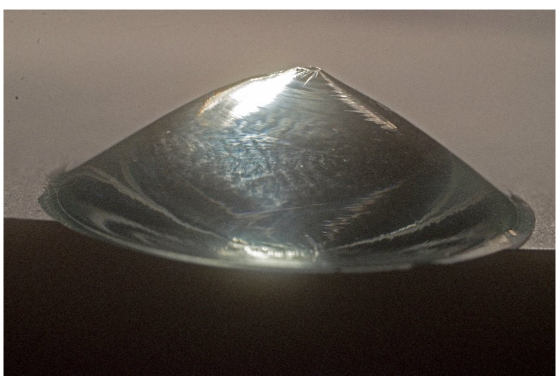

Figure 8 *A pap style cone without overburden.*

V. Pap style cone w/o overburden. (figure 8)

Segments:

1. Crater floor.
2. Crater wall.
3. Possibility for pedestal with tension (crab or braided) cracks.
4. Possibility for feather hackles.
5. Wallner lines possibility.
6. Possibility for flange and/or lobes.

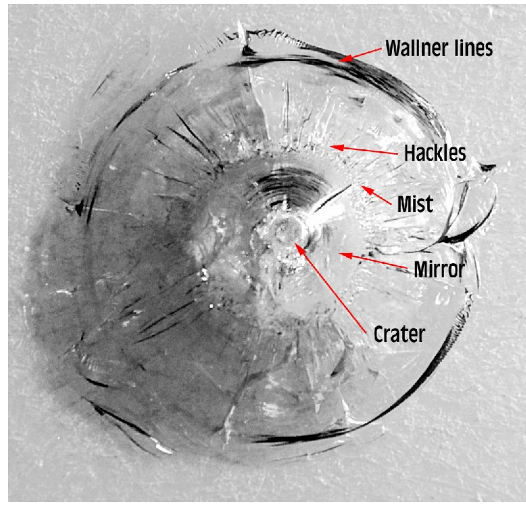

Figure 9 *Classic Hertzian fracture nomenclature; crater, mirror, mist, hackles and Wallner line.*

VI. Classic Hertzian cone including overburden. (figure 9)

Segments with new designations:

1. Crater floor.
2. Crater wall.
3. Rim fractures.
4. Possibility for pedestal.
5. Possibility for tension (crab or braided) cracks.
6. Possibility for feather hackles.
7. Full cone.
8. Mirror.
9. Mist.
10. Hackles.
11. Wallner lines.
12. Possibility for radial cracks.

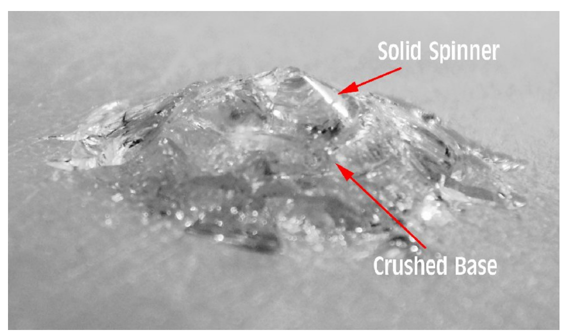

Figure 10 *Partially-crushed, terraced cone. Cones usually fragment from the bottom to the top.*

VII. Partially-crushed cone. (figure 10.)

1. Crater, partially crushed or comminuted floor.
2. Crater wall, crushed with circs and parenthetics.
3. Unfragmented spinner (complete core of mirror segment.)
4. Feather hackles.
5. Mist.

6. Solid central core.
7. Hackles with possibility for Wallner lines.
8. Possibility for laminae over crushed core.
9. Possibility for flange segments.
10. Possibility for multiple mirrors, mist areas and rings of hackles.

VIII. Crushed cone w/o overburden.

Segments: (See figure 1)

1. Crushed crater floor.
2. Crushed crater walls.
3. Crushed spinner.
4. Central core.
5. Feather hackles.
6. One or more layers of Laminae (flakes) with hackles.
7. Exfoliated Laminae.
8. Possibility for triangulate segments.
9. Wallner lines possible on most cone sections.
10. Flake division cracks.
11. Possibility for multiple annular mirror, mist and hackle areas.
12. Possible terracing after overburden is removed (see figure 10.)

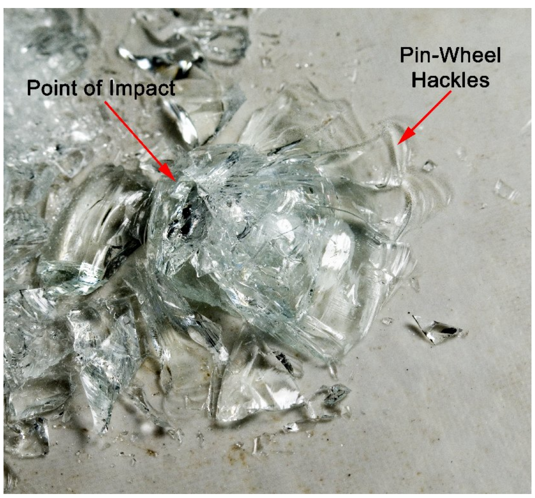

Figure 11 *Fragmented pinwheel cone with lobes.*

IX. Pinwheel cone w/o overburden. (figure 11)

Segments:

1. Crater floor, solid or crushed.
2. Possibility for pedestal .
3. Possibility for tension (crab or braided) cracks around pedestal.
4. Feather hackles possible.
5. Mirror.
6. Mist.
7. Hackles throughout.
8. Wallner lines throughout.
9. Elongated, lobed and divided laminae.
10. Possibility for multiple mirrors, mist areas and rings of hackles

Figure 12 *Shield cone with straight buttress.*

X. Shield cone w/o overburden. (figures 12 & 13)

Segments:

1. Crater floor.
2. Possibility for pedestal.
3. Possibility for tension (crab or braided) cracks around pedestal.
4. Feather hackles.
5. Wallner lines.
6. Possible buttress with winged appendages.
7. Possibility for feather hackles on winged appendages.
8. Possibility for flange, especially on winged appendages.
9. Possibility for multiple mirrors, mist areas and rings of hackles.
10. Possibility for multiple layers of laminae.
11. Possibility of concaved flange.

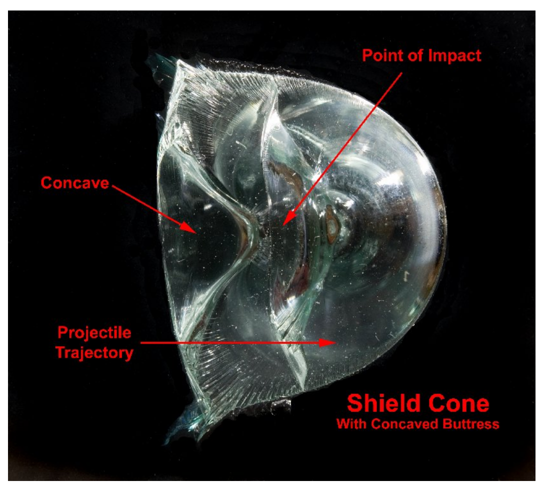

Figure 13 *Shield cones with coved buttresses are indicative of low angle trajectories and/or projectiles with backspin. Here, feather hackles are present on buttress wings.*

XI. Axial cone tilt variants.

1. Chatter marks. Tilted or partial cone created by moving indenter[8] or a projectile with a low angle of attack.

Figure 14 *Chatter Marks in granite, Yosemite National Park. Boulders serve as indenters while scraping across a granite plane creating tilted Hertzian fractures, the base in the direction of flow. Image, G K Gilbert USGS 1903*

2. Backspin. Annular rotation of a projectile on the X-axis counter to the direction of travel. The projectile can deviate upward along the path creating a "U" shaped arc. It can also create back pressure on the target tilting the Hertzian Cone away from the point of origin. With backspin the projectile "digs" into the target the way a golfer uses backspin to hold the ball on the green after a chip shot.

3. Side spin. Annular rotation is around the convergent point of the XY-axis along the projectile's line of travel; clockwise (c-spin) and counter-clockwise (cc-spin). Airplane propellers rotate in this manner to pull the aircraft along its route.

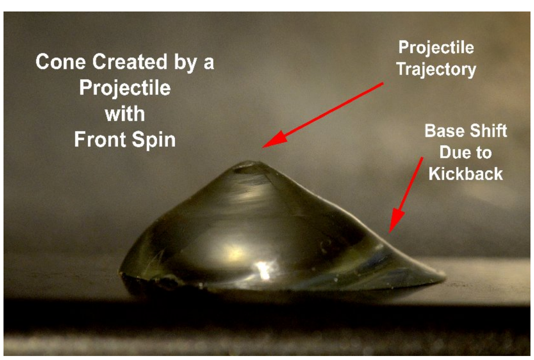

Figure 15 *Front spin can create "kickback" causing tilting of a cone toward the direction of the origin of the projectile.*

4. Front spin. Annular rotation in which the top of the projectile moves in the direction of travel faster than the velocity of the projectile creating a reversed cone tilt.

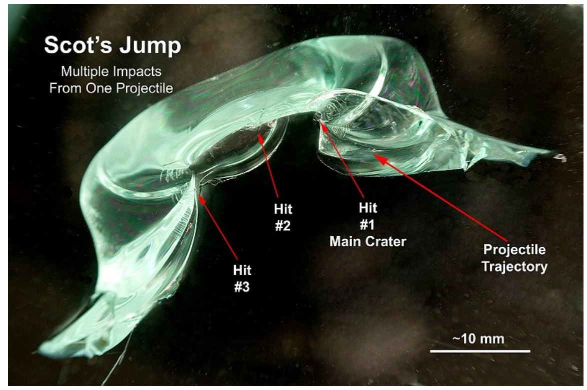

Figure 16 *Scot's jump, multi-impact fractures caused by sidespin rotation.*

XII Multi-impact (Scot's Jump) Hertzian fractures. (figure 16) These irregular-shaped conjoined fractures occur in target material with to multiple impacts in near-simultaneous sequence. They are created by forward spinning and jumping projectiles with the possible inclusion of lateral rotation.

Figure 17 *A star or X-shaped fracture. This sample was from the lower of two layers of glass. The top layer displays a faint "lotus" flower from the impact.*

XIII Star (X-shaped) fractures (figure 17) are created from the bottom of a plane or strata due to projectile or indenter forces bending the area around the point of impact away from force-origin.[9]

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[8] *.Erosional features, Treatise on Geomorphology*, Munro-tasiuk, M.J.,Heyman,J., Harbor,J., 2013.In: Shroder,J. (EditorinChief), Giardino,R.,Harbor,J.(Eds.),. Academic Press, SanDiego,CA, vol.8 ,Glacialand Periglacial Geomorphology,pp.83–99.

[9] Ball, A., McKenzie, H.W., On the low velocity impact behaviour of glass plates, Dept of Materials Engineering, Univ of Cape Town, South Africa, 1994.

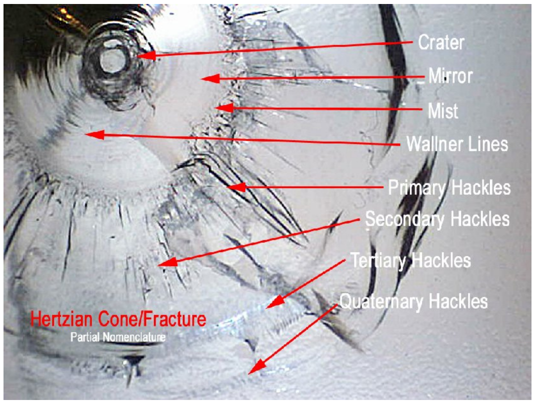

Figure 18 *Hertzian fractures contain many more features than are commonly shown. This image shows multiple repetitions of mirror, mist, hackle areas in the mold section of a compound Hertzian fracture.*

XIV Compound Hertzian fracture cones and molds (figure 18) are created by higher velocity impacts. As the cone is forming bouncing P-waves can divert downward energy to form repetitive annular features.

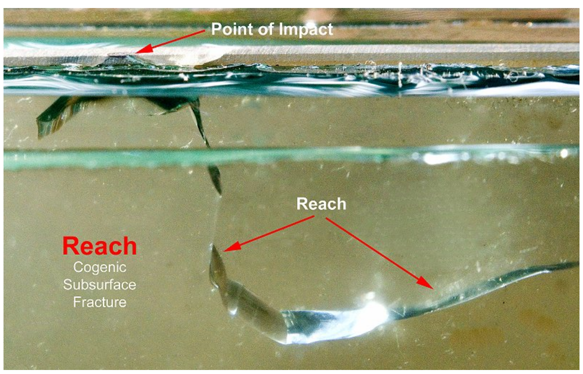

***Figure** 19 A reach is a cogenic subsurface fracture under Hertzian cones that "dive" into the target material.*

XV Reach. Sub-surface fractional features below the base of the Hertzian cone while still in overburden. These features "reach" down in to lower target material many times the original cone depth.

Conclusion

Hertzian fractures, molds and cones contain many more features than are normally referenced. Through table-top experiments varied examples can be created in glass. The probability is high that similar Hertzian features may be found in rock and other crystalline materials. Further studies are needed to record exact rotational causation for differing projectile fractures.

References cited

Aliabadi M.H., *Fracture of Rock.* Chapter 6. Computational Mechanics Publications. 1998. pp. 167-203

Ball, A., McKenzie, H.W., *On the low velocity impact behaviour of glass plates,* Dept of Materials Engineering, Univ of Cape Town, South Africa, 1994

Dong, X.D., Darvell, B.W., *Stress distribution and failure mode of dental ceramic structures under Hertzian indentation*, Dental Materials Science, Faculty of Dentistry, The University of Hong Kong, Prince Philip Dental Hospital, Hong Kong, People's Republic of China, 2002.

Ernstson, K., Claudin, F., *Impact-induced surface hardening of polished quartzite cobbles, Triassic Buntsandstein conglomerates, Northern Spain,* , (2012) http://www.impact-structures.com/2012/07/impact-induced-surface-hardening-of-polished-quartzite-cobbles-triassic-buntsandstein-conglomerates-northern-spain/

Campfield, R., Ultra Bond, Inc., *Facts and Findings about Windshields*, the Insurance Journal, May 1, 2003,**.** http://www.insurancejournal. com/services/newswire/2003/05/01/41550.htm

Miyamoto, A., Murakami, Y., *The Morphology of Hertzian Cone in Plate Glass by Projectile Impact,* The Society of Materials Science, Japan, Vol. 49, No.8, pp867-872, Aug. 2000

Munro-tasiuk, M.J.,Heyman,J., Harbor,J., *Erosional features, Treatise on Geomorphology*, 2013.In: Academic Press, SanDiego,CA, vol.8 ,Glacialand Periglacial Geomorphology,pp.83–99.

Semaw, S., *The World's Oldest Stone Artifacts from Gona, Ethiopia: Their Implications for Understanding Stone Technology and Patterns of Human Evolution Between 2·6–1·5 Million Years Ago*, Journal of Archaeological Science (2000) 27, 1197–1214