# DEFORMATION, ABLATION AND SPALLATION USED TO DEFINE PROXIMAL, MEDIAL AND DISTAL TEKTITE ASSEMBLAGES.

A. Whymark[1], [1]Consultant Wellsite Geologist (aubrey@tektites.info).

**Introduction:** Tektites are defined herein as naturally occurring, holohyaline, macroscopically homogenous droplets formed by the melting and ballistic ejection of silica-rich target rocks by large cosmic impacts. In this abstract only melt droplets and not microscopic condensate droplets are considered. Layered impact glasses, transitional to true tektites, are also excluded from this discussion. Tektites are traditionally included within the bracket of distal ejecta, defined as material deposited at a distance of over 5 crater radii [1]. In the case of Australasian tektites this definition might not hold true in the future, hence the definition of ballistic ejecta instead. This abstract reviews the morphological and sculptural trends that can be observed in tektites with distance from the source crater. Tektites are routinely divided into splashform (normal) tektites and aerodynamically shaped (ablated) tektites. This is an unsatisfactory binomial system used to describe a three-stage process that forms three broad (albeit transitional) tektite morphological groupings.

**Primary Morphologies:** Primary tektite morphologies are considered to be spheres, short prolate spheroids, long prolate spheroids, spheroidal dumbbells and spheroidal teardrops (morphologies with a spheroidal cross section perpendicular to the long axis). These shapes are controlled by fluid viscosity, related to melt temperature (lower temperature proximal tektite assemblages contain far more teardrops and dumbbells). The elongate shapes form due to the speed of (unstable) rotation of the bodies. These morphologies are typically momentary and immediately undergo modification on interaction with the atmosphere.

**Secondary Modification:** Primary tektite morphologies may be acted upon, to varying degrees, by three main modification methods: 1) Plastic deformation through atmospheric interaction whilst molten. 2) Re-entry heating that may lead to ablation. 3) Rapid cooling when inherited cosmic velocity is lost leading to spallation. The velocity and angle of ejection not only determines the distance the tektite will travel, but also has a major influence on the degree of atmospheric interaction the molten tektite has during exit and the severity of heating during atmospheric re-entry. These three factors result in distinct tektite morphological groupings at different distances from the source crater.

*Plastic Deformation:* The molten primary tektite droplets, controlled by surface tension, are immediately acted upon by air friction if they form within the atmosphere. Air friction results in the establishment of internal vortices in the molten tektite. The amount of deformation is controlled by the velocity, the density of the atmosphere (altitude), the transit time through the atmosphere (angle of ejection plus velocity) and the time taken to cool to a point beyond which deformation ceases (size is an important factor). Centrifugal forces play little or no role in the flattening of bodies as evidenced by discoidal teardrops and the lack of discoidal forms in all but the most proximal tektites.

In an oblique impact the first formed, highest temperature, distal ejecta travels at a low angle and high velocity. The molten liquid cascades into smaller and smaller droplets, rapidly reaching very high altitudes due to high velocities. Bodies are typically slightly off-spherical (inferred by being oriented, larger distal bodies can be measured as off-spherical) [2]. This near sphericity indicates solidification at high altitudes.

The second formed medial tektites are ejected at lower velocity, but at higher angles, which, despite the lower velocities, allow rapid transit of the atmosphere. The melt is of marginally lower temperature as the energy of impact is more widely dispersed. Commonly, bodies are flattened from spheroidal to ellipsoidal. Some bodies remain spherical, indicative of no atmospheric interaction at the point of solidification.

The last formed proximal tektites, ejected at the lowest velocities, form discrete bodies at lower altitudes. Despite much lower velocities, the atmosphere is denser at lower altitudes (but still rarefied). Bodies immediately deform in the same way as a raindrop interacts with the atmosphere (in this case a thinner atmosphere and a higher velocity). A good analogy of behavior is a smoke ring. Molten tektites act in the same manner with internal vortices being established as the body passes through the atmosphere. The spheroidal body becomes ellipsoidal, discoidal, then toroidal. Toroidal bodies are unstable and always fragment. Tektites are continually cooling and so plastic deformation and cascading has a limited time to act on the bodies before non-equilibrium forms are ‘locked-in’. Smaller bodies cool quickest and are less deformed.

*Heating and Ablation:* If the tektite re-enters (or never exits) the atmosphere as a molten body then any heating by ram pressure simply maintains the heat of the body and continues the plastic deformation stage for longer. All but the largest medial, and all distal tektites had sufficient time to solidify to a brittle cool body prior to re-entry. Ram pressure then heated the body. With sufficient velocity, in excess of 5 km/sec [3], the temperature generated was sufficient to melt the tektite glass and evidence of laminar and turbulent flow can be seen in the resultant flow ridges. The heating stage is important, even if no ablation occurs, as it is reflected in the subsequent spallation stage.

*Cooling and Spallation:* Once inherited cosmic velocity has been lost the body rapidly cools in the mid to lower atmosphere. This rapid quenching results in brittle failure of the tektite (unless small and thermodynamically stable). Triangular to polygonal shell fragments are lost from the anterior. Even when the anterior has 100% spalled, a tell-tale sign of ablation is left in the form of the core morphology, principally the flaked equatorial zone and ledged rim, marking an abrupt cut-off in surface heating due to the prior presence of a flange protecting the posterior surface.

**Classification:** We have three processes that act upon the tektite, dependent on a number of factors, but for simplicity one could say primarily related to velocity and angle of ejection, also effecting the landing site.

*Distal tektites* (e.g. Australites and Javaites) have minimal (but present) plastic deformation, sufficient re-entry heating to cause ablation (increasing with distance / velocity) and significant spallation. The presence of ablation defines distal tektites, and even when not directly observed it is identified by distinct core morphologies with equatorial margins and ledged rims.

*Medial tektites* (e.g. Philippinites, Billitonites, Bediasites) exhibit a stronger, but variable plastic deformation stage ranging from none to more usually ellipsoidal (never discoidal). They have been heated during re-entry, but not sufficiently for ablation to occur. All but the very largest tektites (which retained sufficient heat to avoid brittle failure) suffered spallation on the anterior surface. Medial tektites are typified by spallation, with no prior ablation (just re-entry heating).

*Proximal tektites* (e.g. Indochinites, Chinites, Moldavites, Georgiaites, Ivorites) suffered minimal to very significant plastic deformation, commonly forming discoidal morphologies. They typically formed within the atmosphere. Due to insufficient time elapsed for cooling and much lower velocities they suffered only minor re-heating and no ablation. Only minimal spallation is observed, commonly in the form of 'bald spots' on the anterior margin and radial cracks indicative of a solidified shell and molten interior.

**Conclusions:** There are three formation processes: Plastic deformation of the molten body during formation within the atmosphere, re-entry heating sometimes leading to ablation, and rapid cooling once inherited cosmic velocity is lost that often leads to spallation. There are consequently three main groups of tektites: Proximal (deformed), Medial (spalled) and Distal (ablated) (Tables 1 & 2). Tektite groupings are transitional and represent a continuous sequence. Study of the Australasian strewnfield leads to artificial divisions caused by geographic gaps where seas separate groups. Distances of proximal, medial and distal tektites from source craters are shown in Table 3.

| Group | Deformation | Ablation | Spallation |
|---|---|---|---|
| Distal | Minimal. | Strong heating with ablation. | Significant, (occasionally none). |
| Medial | Moderate, grading to none. | Moderate heating with no ablation. | Significant, (occasionally none). |
| Proximal | Significant, grading to minimal. | Minimal heating with no ablation. | Minimal to none. |

Table 1: Significance of different processes in proximal, medial and distal tektites. Gray shading shows importance.

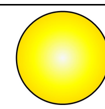
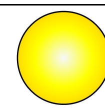
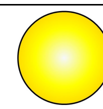
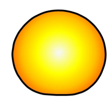
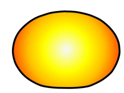
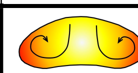
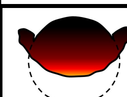
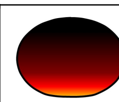
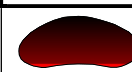
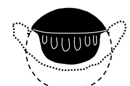
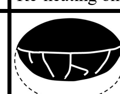
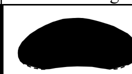
| Process | Distal | Medial | Proximal |
|---|---|---|---|
| Primary |  |  |  |
| Deformation |  |  |  |
| Ablation |  Ablation |  Re-heating only |  Minimal re-heating |
| Spallation |  |  |  |

Table 2: Generalised formation sequence in proximal, medial and distal tektite.

| Strewnfield | Proximal | Medial | Distal |
|---|---|---|---|
| Australasian* | 130-940 | 1290-2500 | 2800-7870 |
| N. American | 635-930 | 1955-2180 | n/a |
| C. American | 540-580 | n/a | n/a |
| C. European | 185-430 | n/a | n/a |
| Ivory Coast | 255-320 | n/a | n/a |

Table 3: Distance in km of tektite occurrence from source crater [4]. * Crater assumed to be in Yinggehai Basin.

**References:** [1] Montanari A. and Koeberl C. (2000). In: Montanari, A. and Koeberl, C. (2000) *Impact Stratigraphy: The Italian Record. Lecture Notes in Earth Sciences. 93:* 57-99. [2] Whymark A. (2012) *LPS, XLIII,* Abstract #1045. [3] Chapman D. R. (1964) *Geochim. Cosmochim. Acta, 28 (6),* 793-806. [4] Whymark A. (2018) *Unpublished database (available by request).*