WERE AUSTRALIAN TEKTITES PLASTICALLY DEFORMED PRIOR TO RE-ENTRY? A. Whymark[1], [1]Consultant wellsite geologist (Unit 30-B, Tower 2, The Columns Legazpi Village, Arnaiz Avenue, cor. Amorsolo Street, Legazpi Village, Makati, 1229, Republic of the Philippines, aubrey@tektites.co.uk)

Introduction: Australites are distal tektites of the Australasian strewn field. Since at least 1935 [1] they have been considered to represent ablated primary spheres (or spheroids), which, in larger bodies, have subsequently spalled to form cores. Whilst sphericity measurements of the posterior surface of australites imply formation from a perfectly spherical body, the fact that, almost without exception, every single australite is oriented is not adequately explained.

Observations: The author has studied the morphology of proximal indochinites and medial philippinites. It is clear that the indochinite primary body immediately underwent plastic deformation resulting in a sphere becoming an oblate spheroid, biconvex disc, concavo-convex disc (concave surface being the anterior), biconcave disc and ultimately a toroid. Dependent on size and cooling history/distance from crater, bodies solidified at various stages of deformation. The deformation process is effectively identical to that of a raindrop cascading sequence, but in a liquid that is rapidly cooling.

Philippinites, found at medial distances, are unique in that they display both oriented 'core' morphologies and un-oriented 'spherical' morphologies. The un-oriented forms must have tumbled during re-entry, spreading the re-entry heat over the entire surface and thus surviving largely intact. The un-oriented spherical morphologies indicate that even the largest philippinites (1,281.89 grams and 1,194.80 grams) were sufficiently cooled on the exterior to resist plastic deformation during re-entry. The largest forms were, however, sufficiently hot on the interior to resist brittle crack formation which is commonplace on the smaller breadcrust forms which cooled throughout prior to re-entry.

The philippinite core morphologies formed by spalling alone as they inherited insufficient velocity for ablation to occur. Small lenticular cores are locally known as 'biscuits' and they have radiating cracks and hertzian/incipient cones on the anterior. Large cores are bifurcated and are locally known as 'hamburgers'. The larger bodies retained more heat and hence the anterior surface contains fewer cracks and no hertzian/incipient cones as it was insufficiently brittle. Initially the author worked on the assumption that core morphologies were formed from perfectly spherical bodies as was assumed to be the case with australites. Hundreds of sphericity measurements were made on posterior surface of philippinite specimens and it became evident that towards the posterior margin the curvature increased. Initially it was assumed that abrasion and etching of specimens was responsible for the increase in curvature at the margin. Measurements of very well preserved, barely etched and abraded specimens, however, dispelled this idea. Some tektites from Davao region, Mindanao and Sipalay, Negros Occidental region, Negros Island, Philippines had indisputably fresh primary posterior surfaces with sharp margins and these also showed an increase in curvature towards the posterior margin. The implication is that core morphologies in the Philippines were not derived from perfect spheres, but from variably oblate spheroids to biconvex ellipsoids. The variable degree of plastic deformation also accounts for why some cores are more globular in morphology. This idea of plastic deformation is further supported by exceedingly rare philippinite teardrop forms. Some teardrop forms clearly show signs of plastic deformation, with the tail swept backwards as is commonplace in proximal indochinites.

Plastic deformation in philippinites could only have taken place during atmospheric exit and not during re-entry. This can be demonstrated in specimens by the presence of cracks (etched to form U-grooves) on the anterior surfaces of philippinites which imply the glass was brittle during re-entry. It is demonstrated by the fact that even the largest spherical un-oriented morphologies resisted plastic deformation during re-entry. Finally, it can be demonstrated mathematically that smaller philippinites would have cooled throughout prior to re-entry (up to around breadcrust size) and larger specimens would have cooled on the exterior prior to re-entry.

Some philippinites were perfectly spherical and therefore formed above atmospheric effects and then, due to their perfect sphericity, re-entered in an un-oriented fashion, thus surviving intact. Other philippinites, in fact the majority, must have been disrupted and formed at lower atmospheric levels, been plastically deformed during atmospheric exit and then re-entered necessarily as oriented bodies.

This conclusion led the author to re-visit australite formation. The sphericity of numerous australites, particularly the larger cores, was measured and as expected the posterior surface implied a perfectly spherical primary body. The clue to australites not being derived from perfectly spherical bodies, however, is that almost without exception all australites are oriented. If australites were derived from perfect spheres then why do we not find un-oriented specimens in Australia as we do in the Philippines? Agreed that australites underwent ablation [2] whereas philippinites did not, but a perfect sphere should theoretically still be unable to find a fixed stable orientation until irregularities arose, if indeed they did arise.

At this point one must return to the rain drop analogy. In the early stages of deformation it is the anterior that is initially the most distorted as it experiences the highest pressures. The posterior surface may flatten slightly, but it will still give the impression of a perfect sphere once the majority of the body had been ablated and spalled away.

Model: The author investigated the ballistic trajectory of Australasian tektites. Numerous assumptions must be made, but in order to account for the distribution and morphology of tektites a fairly narrow range of parameters is concluded. It is suggested that the most proximal (and last formed) tektites at 400 km from the probable crater location in the Bay of Tonkin were ejected at an angle of ~45 degrees and velocity of ~2 km/sec, remaining in the atmosphere and hence being significant plastically deformed. Indochinites at greater distances were ejected at lower angles and higher velocities, perhaps ~35 degrees and ~2.9 km/sec at 900 km distance. These tektites would have exited into ‘space’, but still suffered some degree of plastic deformation during exit.

Philippinites likely exited at the optimum angle of 30 degrees [3], travelling at some ~3.8 km/sec. Javaites may have exited at around 20 degrees and ~5.3 km/sec, sufficient velocity for ablation to occur. Australites, representing the first formed tektites, likely exited at around 10-15 degrees and ~6.5 to 6.9 km/sec.

Using these assumptions one realizes that the philippinites would have made it to the highest atmospheric levels in the quickest times. It is for this reason that philippinites alone have un-oriented perfect spheres in the assemblage. These are the only tektites to have been disrupted above atmospheric effects. More proximal tektites (indochinites) took a more direct route, but the lower velocity resulted in a longer time to traverse the atmosphere, with the most proximal forms failing to even leave the atmosphere. More distal forms (australites) travelled at a higher velocity, but the lower ejection angle meant that they were likely disrupted at lower atmospheric levels when compared to philippinites. Consequently they cascaded into smaller bodies (also related to high temperature/low viscosity) and likely suffered minor plastic deformation, resulting in their orientation during re-entry.

Conclusions: Proximal indochinites suffered plastic deformation during atmospheric exit and in the more proximal setting also during re-entry. Some indochinites never left the atmosphere. Medial philippinites took the shortest time to traverse the atmosphere resulting in some perfect spheres forming in ‘space’. Perfect spheres tend not to gain a fixed orientation during re-entry and thus do not spall, landing as perfect spheres. Some may gain a late-stage orientation. The majority of philippinites, however, were oriented and formed at an atmospheric height where interaction with the atmosphere resulted in varying degrees of plastic deformation. Plastically deformed bodies necessarily have a fixed orientation during re-entry and consequently the bodies spalled to form cores.

Australites, whilst giving the appearance of forming from a perfect primary sphere, are almost always oriented. This suggests that australites also underwent minor plastic deformation during atmospheric exit. The australite re-entry body was therefore not technically a primary body as it had already been altered from its perfect spherical shape during atmospheric exit. It is envisaged that, following disruption of the melt, australites underwent cascading and subtle plastic deformation in exactly the same way as raindrops, but were quenched prior to reaching equilibrium morphology. Following ablation and spalling, where applicable, the remnant posterior surface of the australite gives the impression of a perfect spherical body.

If australites were plastically distorted during atmospheric exit then the amount of ablation that occurred is reduced and this will have an impact on calculated re-entry angles/velocities for australites [4].

References: [1] Fenner C. (1935) *Trans. R. Soc. S. Aust., 59,* 125–140. [2] Chapman D. R. et al. (1962) *NASA Tech. Report R-134*. [3] Artemieva N. A. et al. (2002) *Bull. Czech Geol. Surv.*, *77 (4)*, 303-311. [4] Chapman D. R. (1964) *Geochim. Cosmochim. Acta, 28 (6),* 841–880.

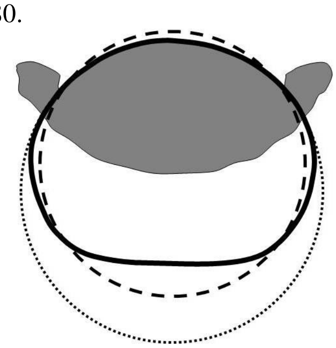

Fig. 1: An impression of how an australite forms from a plastically deformed primary body. Deformation may have been more subtle than depicted. Large dashed line represents the transient primary body. Solid line represents plastically deformed body. Grey area represents australite after ablation. Fine dashed line represents apparent sphericity of the australite.