New results from Apollo program science

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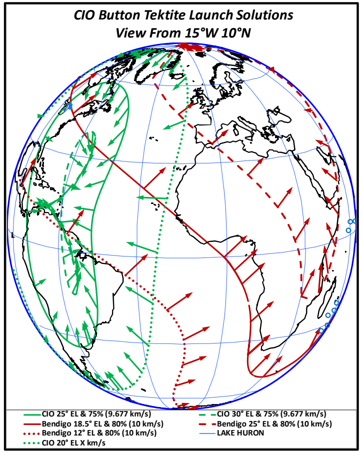
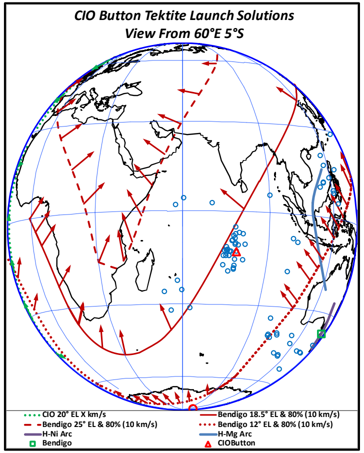
Abstract

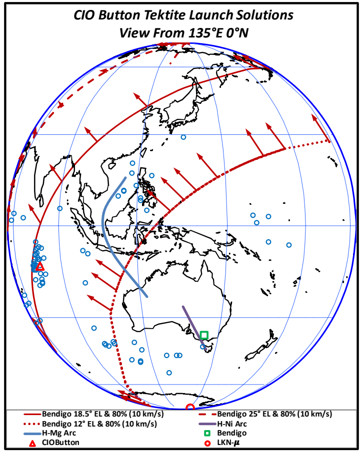
Apollo lunar missions remain the most ambitious manned spaceflights in history, five decades after their conclusion. Apollo free-return mission design atmospheric reentry speeds reached 11.1 km/s, or 98.66% of Earth escape kinetic energy. Heat shield testing at such conditions was a major challenge, requiring high-reliability science. The 1960s solution involved analytic equations with numeric simulation, both verified by hypervelocity plasma arc jet lab testing, a triple standard for reliable design. Researchers at NASA Ames used tektite specimens for the task. This mostly silicate cosmic impact ejecta melt had been blasted into space, vacuum quenched during an extended loft, and naturally ablated from a cold initial state during atmospheric entry. After carefully reproducing Australasian tektite glass, spherical samples were exposed to arc jet conditions simulating near-escape speeds and upper-atmospheric conditions. The NASA scientists were able to control ablative effects at those extreme speeds to exactly match condition-sensitive features found on the natural tektites, including anterior face ring waves and flange flattening in addition to overall mass loss. Reproducing morphologic features of naturally ablated tektite via hundreds of tests over several years allowed D. R. Chapman to tune coefficients of the heat transfer equation describing hypervelocity transit from the free molecular to the collisional regime of the upper atmospheric column. The NASA Ames team determined ablated tektite reentry speeds and vertical flight path angles, and the 'Chapman equation' is still used for modern spacecraft heat shield design, a win-win for NASA's Apollo program. In an error of omission, the same team never accounted for longitude shift due to 3.5 to 11.5 hours of Australasian tektite loft at those reentry speeds in order to determine regions of possible terrestrial origin. Instead, they promoted lunar origin. Terrestrial origin of tektites became clear after lunar sample return, while lunar origin of tektites led to mistrust of Chapman's tektite reentry conditions, a case of throwing away the baby with the 'lunar origin' bathwater. Today, dynamically correct assessment of the A-given-B suborbital problem reveals the Australasian tektite source as roughly coincident with the N. American Great Lakes.

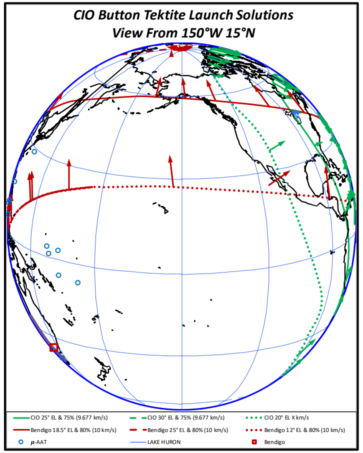
NEW RESULTS FROM APOLLO PROGRAM SCIENCE

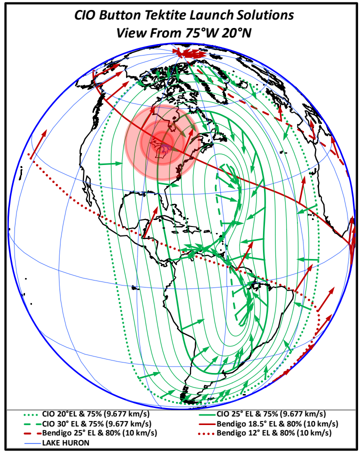
Thomas H. S. Harris, GE AstroSpace, Lockheed Martin, Boeing Helicopter, retired











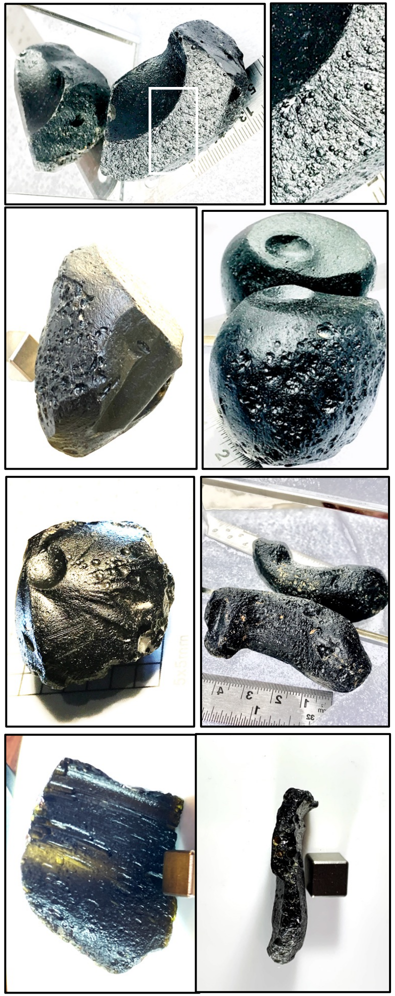
Ablated Australasian tektite (AAT) reentry conditions at disparate fall locations allow AAT source location mapping via A-given-B (inverse) suborbital analysis

Suborbital Analysis (SA) of the Australasian Tektites

- Formal suborbital analysis of Australasian tektite transport based on reentry ablation conditions was not performed by the 1960s tektite researchers at NASA [confirmation bias for lunar origin during president Kennedy's lunar mandate].
- NASA researchers assumed the tektites must have come from an ET source somewhere nearby Earth, i.e. the Moon. Lunar origin champion J. A. O'Keefe at NASA because of:
  - 1) the high energy indicated by the extraordinary scale of the known AAT strewn field in the 1960s,
  - 2) the lack of identifiable young impact structure of ~300 km diameter terrestrial impact structure somewhere on continental landmass, and
  - 3) atmospheric entry speeds approaching (straddling?) Earth escape speed.
- NASA's 1960s ***error of omission*** of any rotating frame transform to account for Earth's rotation during ejecta loft was not identified until 2017 (Harris 2022, GSA Special Papers vol. 553, ch 23, open access), with results of correct treatment outlined here.

Australasian Tektites (AAT)

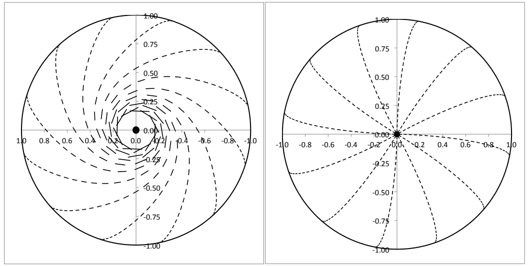
- Tektites follow suborbital laws of motion, <u>not</u> ejecta blanket distribution pattern (NASA's 1960s error of omission).
- 30 to 60 Billion tons distal impact ejecta melt glass, devolatilized, vacuum quenched.
- 789 ka mid Pleistocene Transition Impact ejecta melt, from a fine-grained, near-surface (<2m depth: $^{10}Be/^{26}Al$) shocked silicate sediment w/ a rare unmelted zircon of 1.6 Ga provenance.
- AAT event is co-eval with Precursor signal of the Brunhes-Matuyama geomagnetic reversal.
- Global climate cycle change from 40 ka to 100 ka, and benthic extinctions apparently started *before* 789 ka and ramped up to then, implying inner solar system contamination by a short or medium period comet(?).
- Central strewnfield region is S. E. Asia, microtektites to Antarctica, Madagascar, ¼ of Earth's surface?
- Compositional trends are well characterized, melt is relatively uniform w/ uniform Fe oxidation, implying a much larger transport momentum flow jetting paradigm than N. American tektites per T. H. S. Harris (2022 a,b) LPSC 53, & extended melt exposure to 45,000°K Oxygen ion donor reservoir: 10 km/s delta-V imparted upon ~0.17 cubic km of comminuted sedimentary surface target mass.
- Reentry at 10 km/s implies shock to that speed, & silicate vaporization. How does partitioning allow non-vaporized melt to reach 10 km/s? (not all of the delta-V was from shock, volatiles implied!)
- Fragment-form AAT evidence *post-solidus* high-voltage arcing alteration per T. H. S. Harris (2021 a) LPSC 52, along with uniaxial compression & extension trends consistent with magnetic pinch & pull.
- Extended electromagnetic (EM) action suggests ionized target mass volatiles (i.e. disrupted H_2O ice).
- EM 'rail-gun' effect may have altered transport KE via +/- delta-V, per Harris (2021 a) LPSC 52.



Suborbital Analysis (SA) & Ejecta Fall Patterns:

Harris (2022) Suborbital Ejecta Fall Patterns (Upper Images) Vs. Dobrovolskis (1981) In Lower Frames.

Fall Pattern Convolution From Planetary Rotation Varies By Launch Latitude:
Higher Launch Kinetic Energy (KE) Typically Produces Fall Pattern 'Folds' & 'Wrap-Around'.
Moldavites, Ivory Coast and North American or Chesapeake Tektites Fall Mostly Within Dobrovolskis' 3 Rings (15%, 30% and 45% Escape KE). AAT From N. America Are > 2x Beyond Dobrovolskis' Outer Ring (~80% Escape KE Or More).



Compare to Dobrovolskis (1981) GRLetters

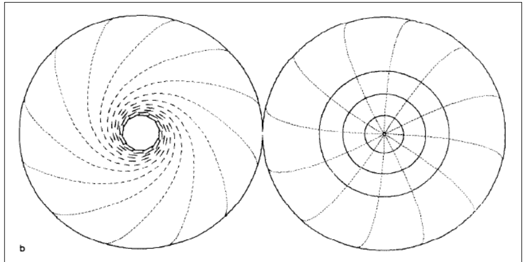
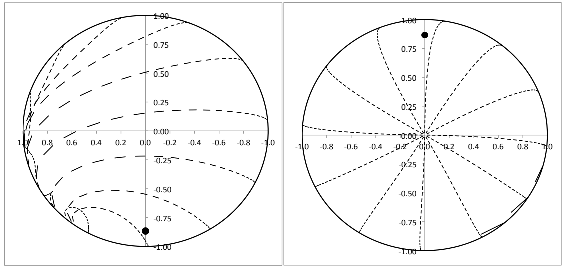


FIG. 6. Same as Fig. 5, but for an impact at the north pole of a planet rotating at the dimensionless rate (a) $\omega = 0.01$; (b) $\omega = 0.05$; (c) $\omega = 0.25$; (d) $\omega = 0.50$.



Compare to Dobrovolskis (1981) GRLetters

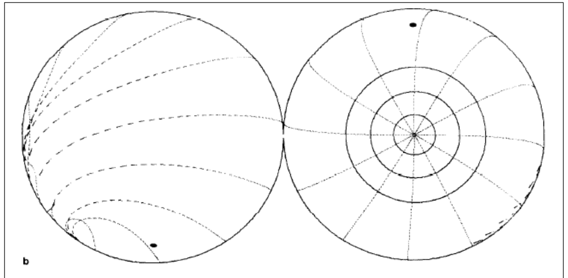


FIG. 9. Same as Fig. 8, but for an impact 60° away from the north pole.

Suborbital Analysis Of Australasian Tektites (AAT)

- Different fall sites & reentry conditions of **two ablated button tektites** allow determination of **possible and impossible regions of terrestrial origin.**
- Reentry conditions for **S.E. Australia** (1962, '63, '64) and the **Central Indian Ocean** fall sites (Glass et al., 1996) were characterized by NASA specialist Dr. Dean R. Chapman.
- The data may be **back-solved** for possible launch locations that generate the various observed reentry conditions and fall locations. The method may be analytical with **a strategy similar to the 'inverse problem' of geophysics profiles**, or iterative numerical.
- Candidate launch solutions were produced using automated control of a numeric suborbital solver per **Harris (2022) below. Reviewers include Walter Alvarez, A. Dobrovolskis, T. R. Howe III, D. T. King Jr., GSA Special Papers 553, Jan 2022**.
- The simplified two-body orbit model is **precise but not accurate** (compared to Earth's aspherical geodesy). **Suborbital Analysis for the tektites is about trends & relative relations of multiple fall sites.**

1960s NASA research recreated sensitive features of ablated tektites to determine their reentry conditions, but omitted the rotating frame conversion required at those speeds, ≥ 10 km/s or ~80% of Earth's escape KE.

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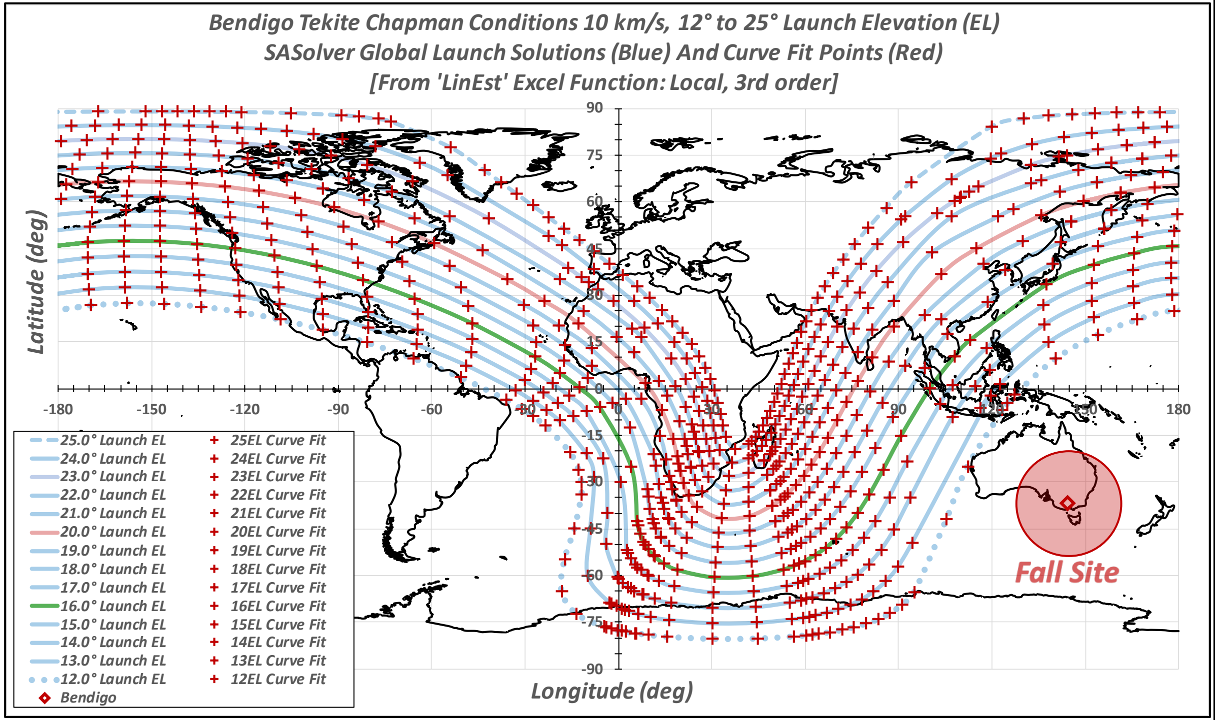
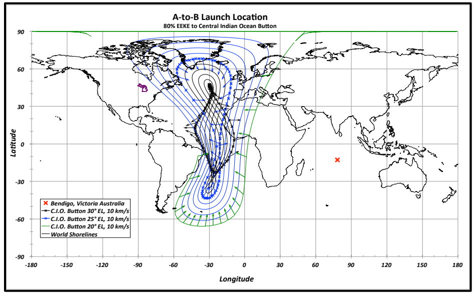
Suborbital Analysis Of Australasian Tektites (AAT)



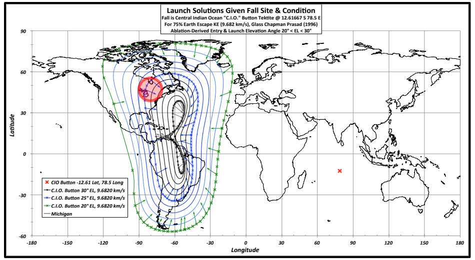
- The **best-characterized or most constrained reentry case** for S.E. Australia ablated 'button' tektites is for high ablation specimens of the Port Campbell repository from the **Bendigo** region, the red diamond at lower right, per Chapman & Larson (1963).
- Launch solution curves fitting **10 km/s speed and 12° to 25° elevation (EL) are shown for 1° EL increments**, with the most likely launch being in the midrange of those values, center of the swath on the map.
- One case alone doesn't narrow down the possible region of origin very well at all – **another specimen with different fall site and/or different fall conditions is needed** to find intersecting launch regions over continental landmass….

Suborbital Analysis Of Australasian Tektites (AAT)

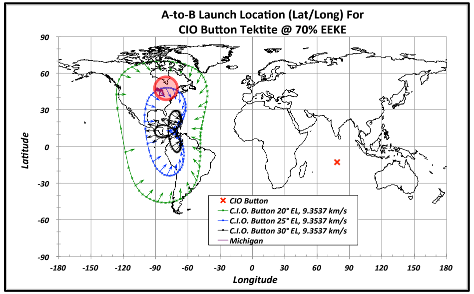
80% Escape KE

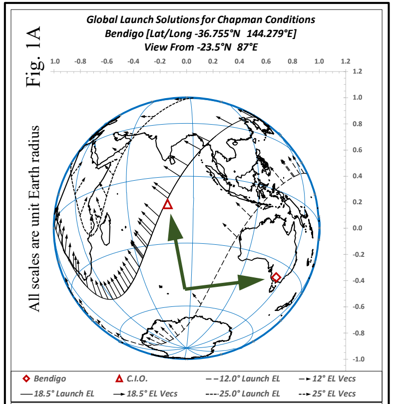


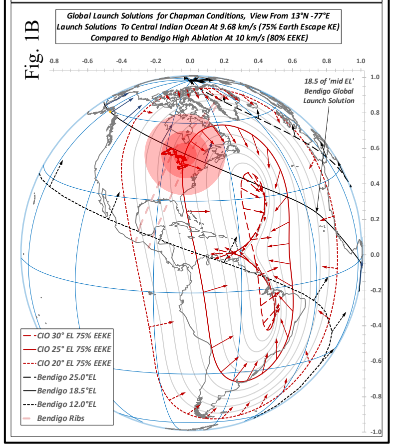
75% Escape KE



70% Escape KE

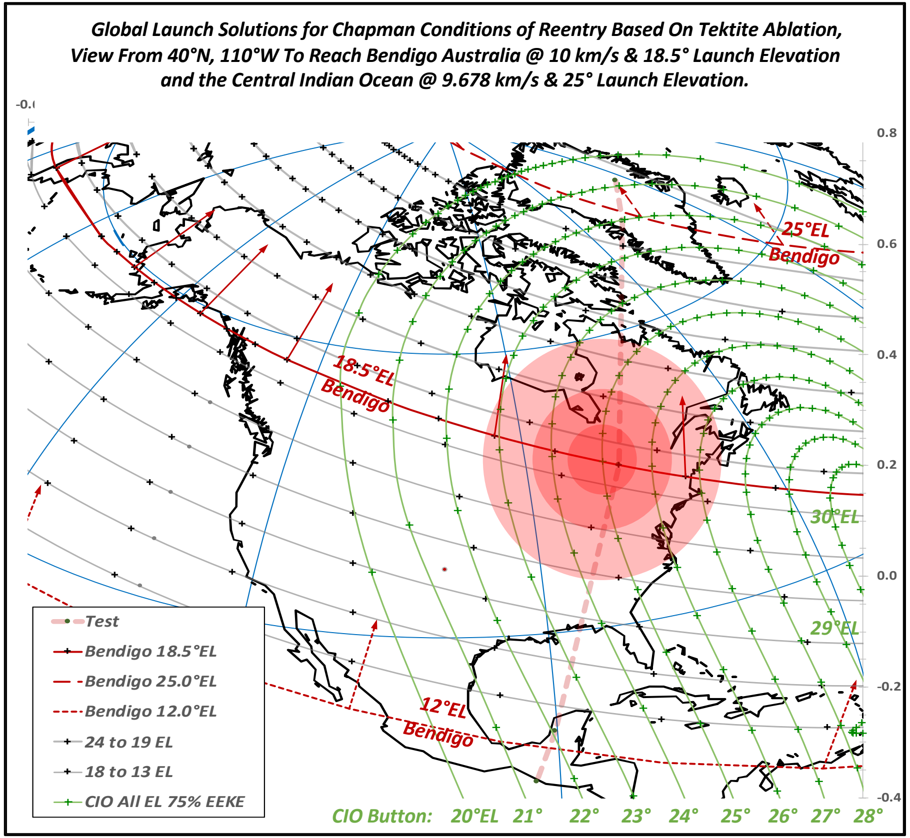


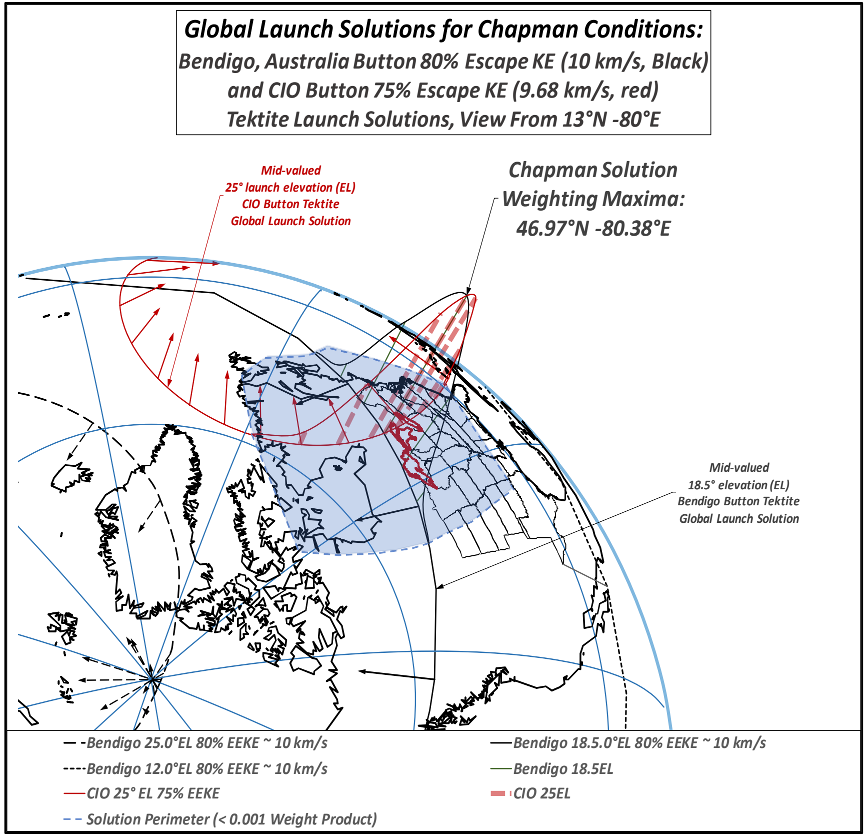




- A well preserved Australasian ablated 'button' tektite was found in the **Central Indian Ocean (CIO)**, per Glass, Chapman, Prasad (1996).
- The **CIO button** reentered at **less speed than the Bendigo** ablated button tektite, and **between 20° and 30° elevation**. There is no known way to determine azimuth of a tektite fall.
- The CIO ablated button tektite case narrows down the possible region of AAT origin. "Chapman condition" (per Chapman '62-3-4) **launch solutions for the CIO button and the Bendigo button intersect at right angles over the N. A. Great Lakes.**
- This is **derived directly from physical evidence of the tektites themselves**, along with analytic, numeric & test results on tektite ablation, and from the physical mechanics that govern suborbital motion. ("…it's the law…")
- **Implication: we have focused the AAT source search on the wrong side of Earth for 5+ decades based on an error of omission made repeatedly in the 1960s and missed until now.**

Suborbital Analysis Of Australasian Tektites (AAT)





Modified from Harris, LPSC 52 (2021)

Summary Points….

1. The Australasian tektites are **extraordinary in mass & coverage**, 30 to 60 billion tons of vacuum quenched distal ejecta melt glass over ¼ of Earth's surface.

2. Fragment-form Australasian tektites often show **multiple clues of this electromagnetic formative paradigm in a single specimen.** Exploded grenade-fragment morphologies are identical to flash thermal cycling & deformations of HV arcing damage.

3. Cosmic KE partitioning over Lake Huron & the 'peripheral' N.A. Great Lakes is implied. No traditionally shaped 'crater' of this scale & epoch exists on continental landmass. **Could ice be responsible?**

4. Correcting NASA's 1960s error of omission leads to the '**Lake Huron Partitioning**' hypothesis.

5. Follow the energy trail, solve the mystery. Is there any remnant physical evidence of cosmic KE partitioning within or around the Michigan Basin and surrounding landmass? What might such evidence look like [**THERMAL ALTERATION**]? Is the mid Pleistocene regolith injection a good candidate here"

6. **Not every impact structure has to look like 'a crater',** as Stickle, Schultz (2012) and Schultz, Gault (1990) teach us. The odd ones may teach us the most if we look carefully enough to find them. Is the giant parent astrobleme of the Australasian tektites actually right here in North America while simply **too big and too shallow to see?**

7. Large-scale KE partitioning should leave plenty of imprint at the scene. ***Can Lake Huron actually be an impact structure convoluted by an ice sheets at 789 ka and further modified by subsequent continental ice sheet scouring cycles?***

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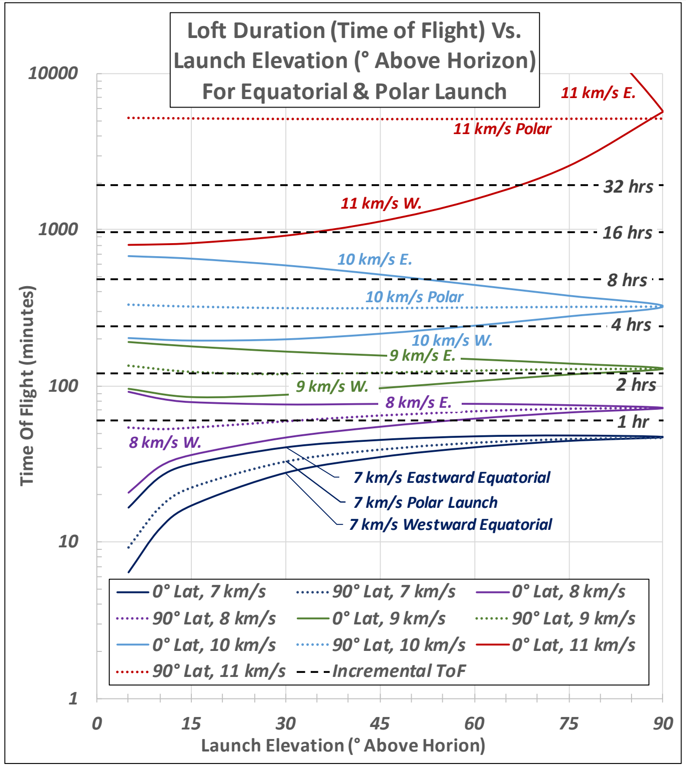
Appendix 1: Suborbital Analysis Of Australasian Tektites (AAT)

AA tektite launch/reentry conditions of 10 km/s (80% of Earth's escape KE) imply intercontinental transport. The AA tektite source region is more likely antipodal to S.E. Asia than it is within S.E. Asia….

- **Loft duration is mechanically dictated** by the orbit state, a direct result of **launch condition and location.**
- Orbit planes are inertially fixed in space, while Earth rotates beneath. This convolutes the fall patterns of ejecta at larger fractions of escape energy: **loft duration expands geometrically with launch kinetic energy (KE) and so does westerly perturbation of ejecta fall as a result**.
- AA tektite launch/reentry conditions of 10 km/s (80% of Earth's escape KE) virtually guarantee intercontinental transport. **The AA tektite source region is more likely antipodal to S.E. Asia than it is within S.E. Asia….**
- Its not just a good idea. It's the law.

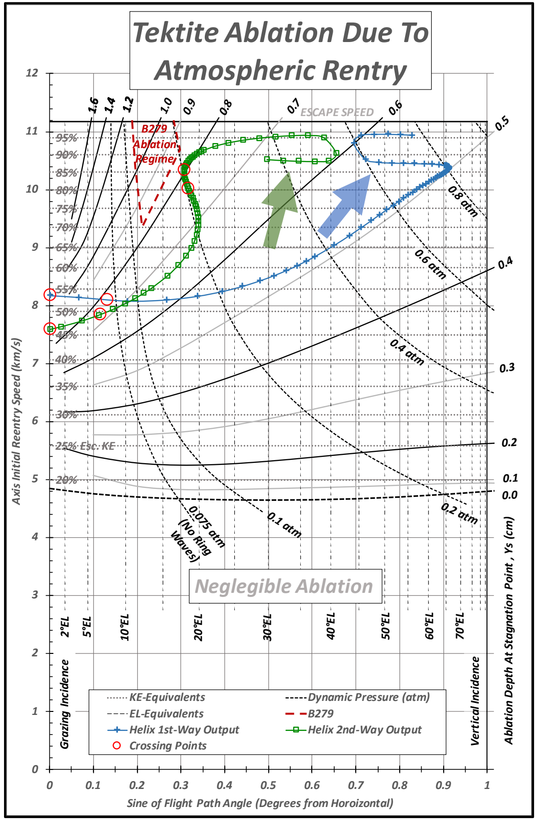


The 'Chevrons of Truth'

Appendix 1: Suborbital Analysis Of Australasian Tektites (AAT)

Spreadsheet 'Helix' is useful for reentry regime comparison of ablated button tektites, run once per geographic grid point in the possible source region map per next slide, lower right.

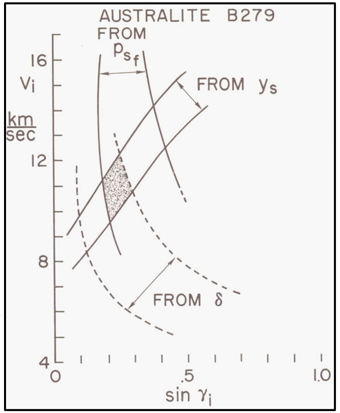
- A test launch location or tektite source produces a set of possible ***A-to-B*** suborbital solutions reaching some button tektite fall point ***B***.
- The set of possible ***A***-*to*-***B*** solutions must intersect a sub-regime of ablation conditions exhibited by button tektite specimens at that fall point, based on extensive hypervelocity testing by NASA in the 1960s.
- If no intersection of suborbital solutions exists with the given ablation sub-regime, the candidate launch location is discarded and the next point in the search grid is processed. Several regimes like *B279* are specifically identified in the literature (next slide).

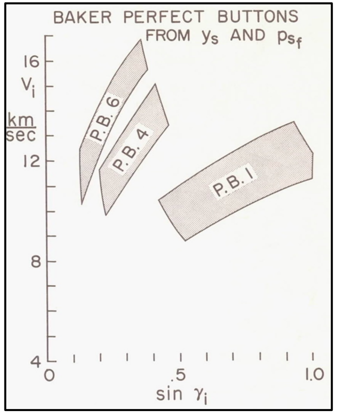


- The ***A***-to-***B*** suborbital problem lies within Suborbital Analysis, a subset of Orbit Analysis where the trajectory ellipse intersects Earth's surface at launch and fall points ***A*** and ***B***.
- The opposing 'loop-back' or bi-directional nature of the blue 1st-Way and green 2nd-Way suborbital solutions is due to Earth's rotation becoming substantial during extended loft duration of ejecta, especially for Kinetic Energy (KE) at and above 80% of escape value. 1960s NASA research missed this, declaring lunar origin of the tektites

Appendix 1: Suborbital Analysis Of Australasian Tektites (AAT)

From NASA Tech Note D-1556, Chapman & Larson (1963)





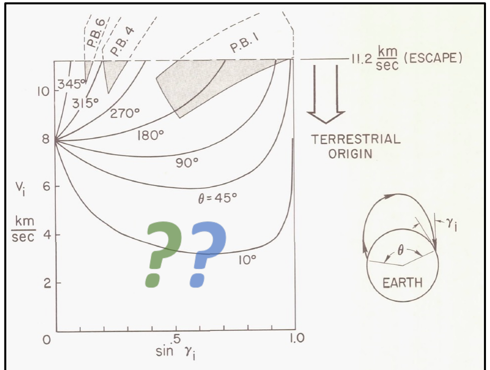
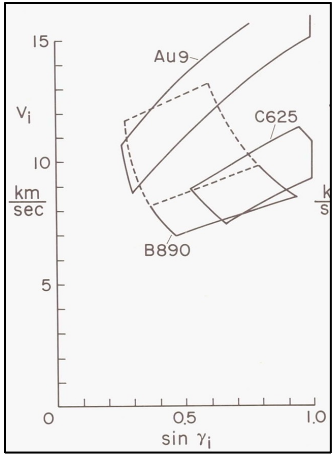
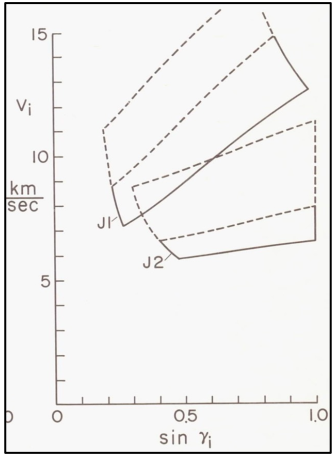


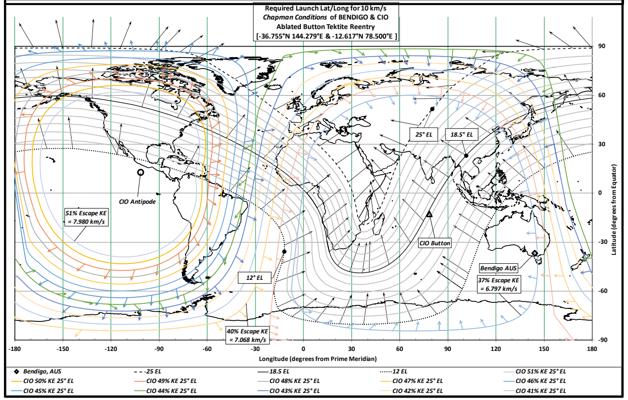
Figure 23.- Test of terrestrial origin hypothesis.

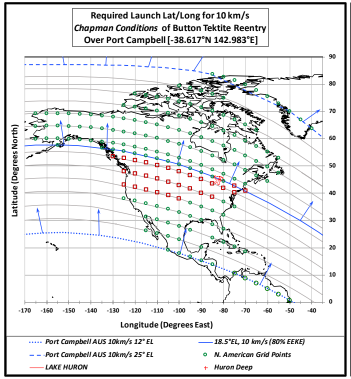


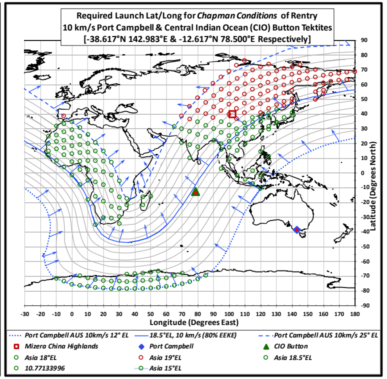


Above, the inertial trajectory setup, ignoring Earth's spin. In reality, multiple ablation regimes (left) must be compared across a global grid (right) to find possible and impossible source regions for the AAT. Grids shown are incomplete, representing the idea of the exercise. The simplified 2-Body gravity model does not treat finite boost, which may sometimes be spline-fit to 2-Body results.

This map highlights the unconstrained extent of possible CIO button tektite KE as a % of escape KE.

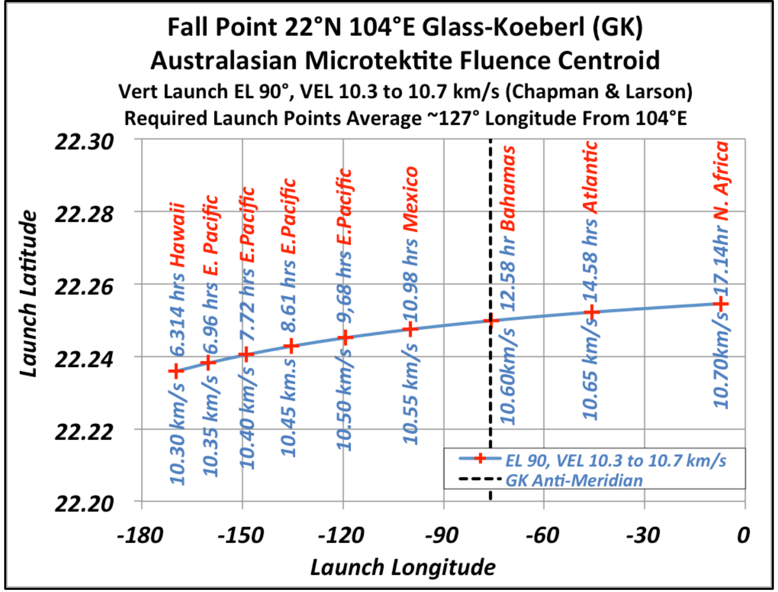






Appendix 1: Suborbital Analysis Of Australasian Tektites (AAT)

Below: The ***A***-given-***B*** suborbital problem is solved for the concentration or 'fluence' centroid of Australasian microtektites as a representative fall point ***B***, to find required launch points ***A*** for vertical launch at different speeds. Ablated button tektites from Australia are known to have reentered at or above 10 km/s (80% escape KE). AA Microtektites are assumed to have had even higher speed. Source ***A*** anywhere near GK fall point ***B*** is not consistent.



Right: The inverse suborbital problem (***A***-given-***B***) solved for the Glass, Koeberl (2006) microtektite fluence centroid using a nearly vertical launch of 83.9° elevation produces a cusp, the thick black dashed curve, 90° through 270° launch AZ. Jetting from Lake Huron with a spread through this range of launch conditions effectively populates the AA microtektite distal ejecta strewn field via spatial dispersion at such elevated launch KE values.