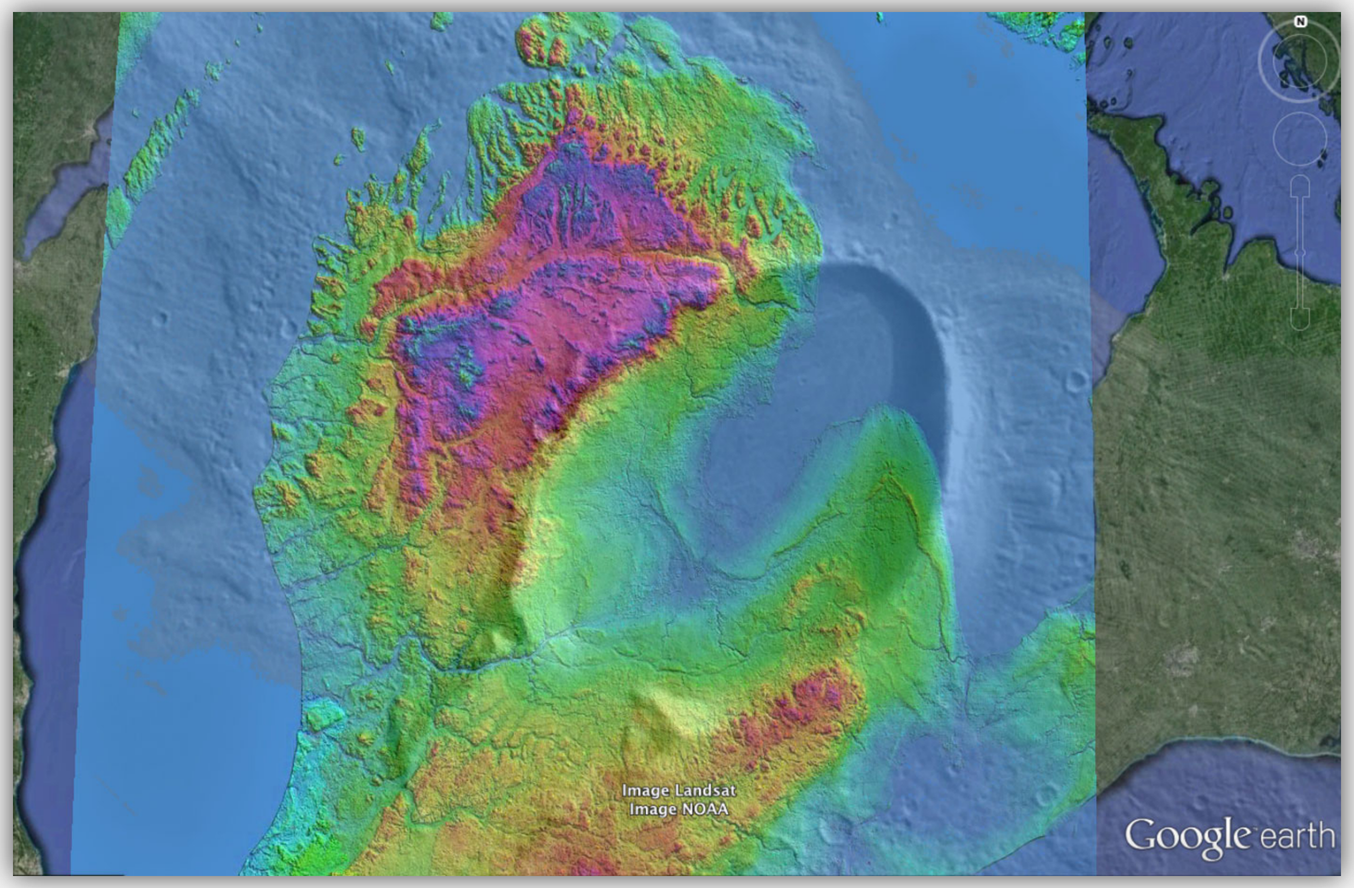
A Tale Of Two Craters:

Coriolis-aware Trajectory Analysis Correlates Two Pleistocene Impact Strewn Fields And Gives Michigan A Thumb



Paper 3-1 Session T 10

2015 GSA North-Central Section Meeting
Madison, WI 19 May, 2015

Michael E. Davias
Thomas Harris

Goals of Talk

- **Puzzle – Australasian Tektites – Missing Pleistocene Crater**
- **Puzzle – Carolina bays – Missing Pleistocene Crater**
- **Puzzle – Michigan's Thumb – Anomalous Glacial Erosion**
- **What we measured**
- **What others have measured**
- **Correlations between the three enigmas**
- **All work product freely available @ www.cintos.org**

Cosmic impacts during the Pleistocene have been implicated in the geomorphology of two enigmatic events, and spirited debates remain unsettled after nearly a century.

Goals

Consensus opinion holds that the Australasian tektites are of terrestrial origin despite the failure to locate the putative crater, while a cosmic link to the Carolina bays is considered falsified by the very same lack of a crater. Considered to be 30 to 120 km in diameter, these impacts during **geologically recent** times should be detectable on the Earth's surface.

And, – Just *How **did** Michigan get its Thumb*? , as it lies at the epicenter of our conjecture that these three puzzles represent a **unique, singular event.**

Myrtle Beach, SC

- ©Fairchild Aerial Surveys for the Ocean Forest Company: Aerial view taken in 1930 (12x8 km)

The “Carolina bays”, first visualized in aerial photography in the 1930s, are shallow depressions that exhibit a closed circumpherial quartz sand rim, ovoid planform, and a common local alignment. Theories put forth have included fish nests and impacts by swarms of meteorites – geologists today prefer “wind & wave”.

Alaskan Tundra Freezes   Thaw Lakes

Although "aligned", these Freeze-Thaw lakes in Alaska display facets of randomness typical of gradualistic processes, and fail comparison to the Carolina bays, which represent collection of robustly similar landforms, suggesting the actions of a **unique, singular event**.

Myrtle Beach, SC

"No one has yet invented an explanation which will fully account for all the facts observed"

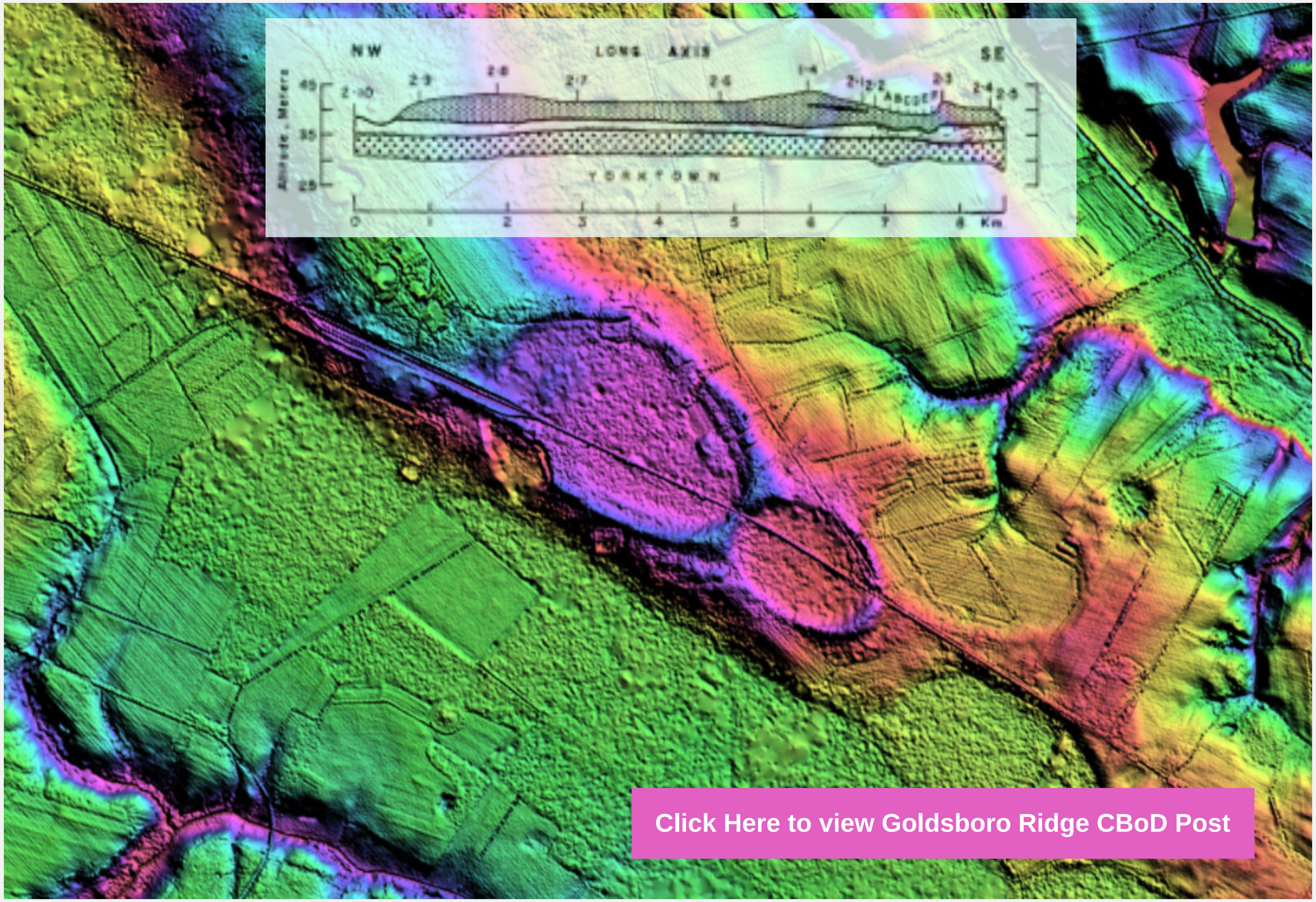
Douglas Johnson, 1942

The Origin of the Carolina Bays

- ©Fairchild Aerial Surveys for the Ocean Forest Company: Aerial view taken in 1930 (12x8 km)

In 1942, Douglas Johnson made this observation after studying all the proposed solutions. His assertion remains accurate, so I invented a novel explanation: they are surficial artifacts in a blanket of pulverized sandstone flowing from a distant cosmic impact.

Goldsboro Ridge, NC



This solution was informed by Raymond Daniels' description of the Goldsboro Ridge. "Even the Carolina Bays do not disturb the underlying Sunderland materials.... The sand in the bay rim is not different from the Goldsboro sand. Therefore, these Carolina Bays are merely surface features associated with the formation of the ridge." This cross section graphic documents the only known attempt to deep core a Carolina Bay. The small number of corings done since are all subs bay in scope and may only penetrate newer surficial sediments.

Riddle *of the* Carolina Bays

BY KEVIN KRAJICK

AS FAST AS SHE CAN MANAGE, SOUTH CAROLINA ZOOLOGY GRAD student Lisa Carswell, 24 years old and five feet tall, is hurdling fallen trees, butting through thick bushes and sprinting in thigh-deep water while grasping a butterfly net that's a lot longer than she is. Her eyes never leave the prey. "C'mere, buddy," she says, suddenly swinging like a major league batter at something small and airborne. Today she might get lucky and perhaps snag a rare insect never seen around here. Maybe even an unknown species. "You never know," she says.

"You never know" is a good motto for the Carolina bays, the locale for her hunt. The confusingly named bays are not ocean inlets; nor are they confined to the Carolinas, though that is where they lie thickest. They are eerie wetland depressions scattered across the Eastern coastal plain from southern New Jersey to northern Florida. Most of them are perfect ovals; they are ringed by ridges of sand as high and dry as their interiors are low and swampy; and all point the same way, northwest to southeast. They have long fueled weird local folklore, bewildered geologists and scared off most everyone else.

Today Carswell is inventorying butterflies, dragonflies and damselflies in bays—the first such study in a region settled for close to 300 years. That's because few biologists want to go in there: bays are often surrounded by, or even filled clear through with, impenetrable walls of shrubs and 12- to 30-foot-

Article by Kevin Krajick, Smithsonian Magazine, September 1997

This is the interior of Antioch bay, one of a Precious few well--preserved bays. Ditching and draining have altered the vast majority; those that remain in their natural state are

….

Riddle of the Carolina bays





Photos: Cameron Davidson, Smithsonian Magazine, September 1997

… sanctuaries of exotic flora and fauna. Unfortunately, the US Supreme Court has ruled that isolated wetlands such as these to not qualify for protection under the Clean Waters Act.

Riddle of the Carolina bays

Carnivorous Dionaea muscipula (Photo: Wolfgang Stuppy)

The Venus Fly trap is found **only** in Carolina bays, providing a clue to the bays' longevity as closed ecosystems.

Major axis of bays change “statistically by latitude”

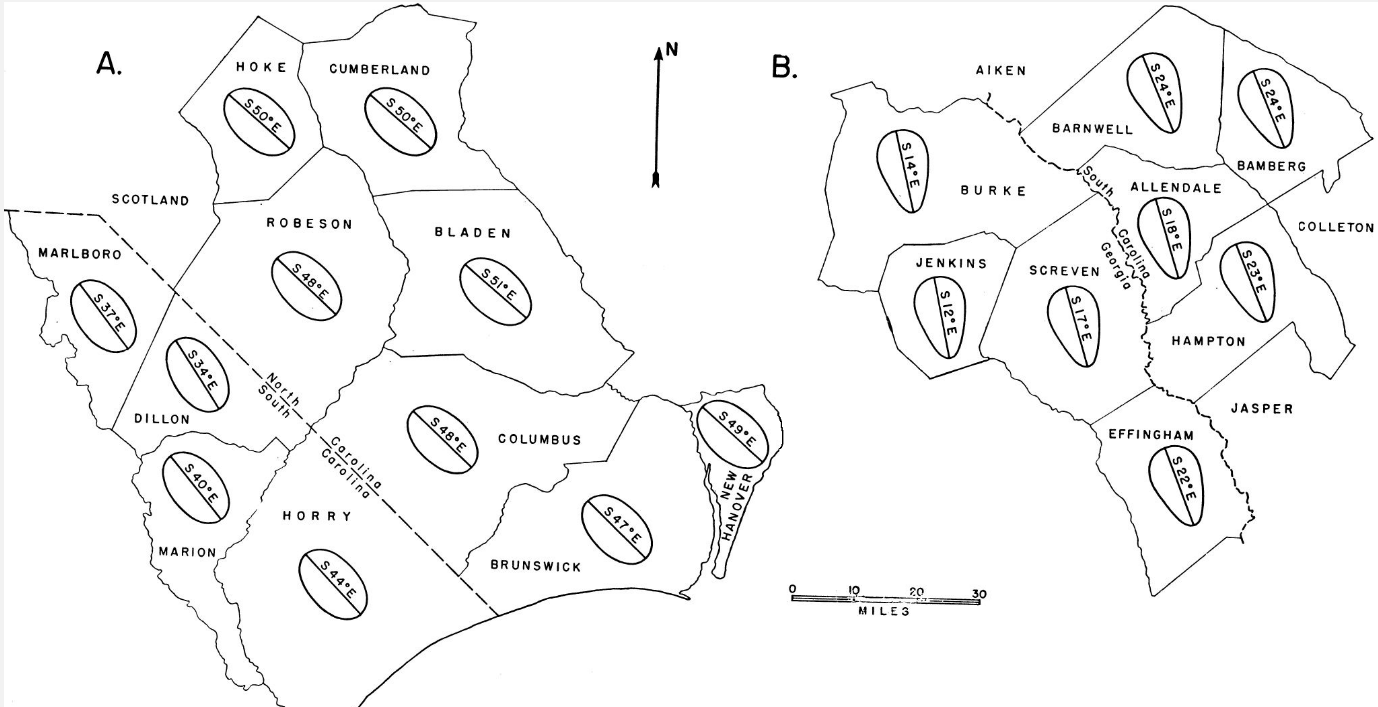
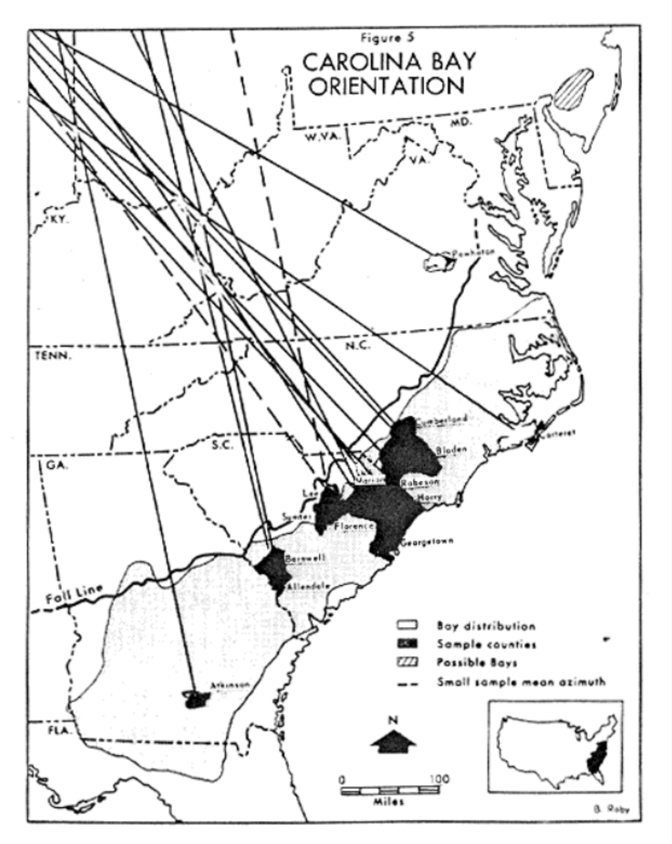


FIGURE 27: Axial trends of basins in northern (A) and southern (B) parts of area of abundant oval bays.

D. Johnson, 1942

Early on, it was noted that the orientations change “statistically by latitude”. Perhaps they capture the arrival vector of an ejecta blanket. Or **not**, but lets discuss the triangulation those orientations advise.

Bays Rotate Clockwise from North to South

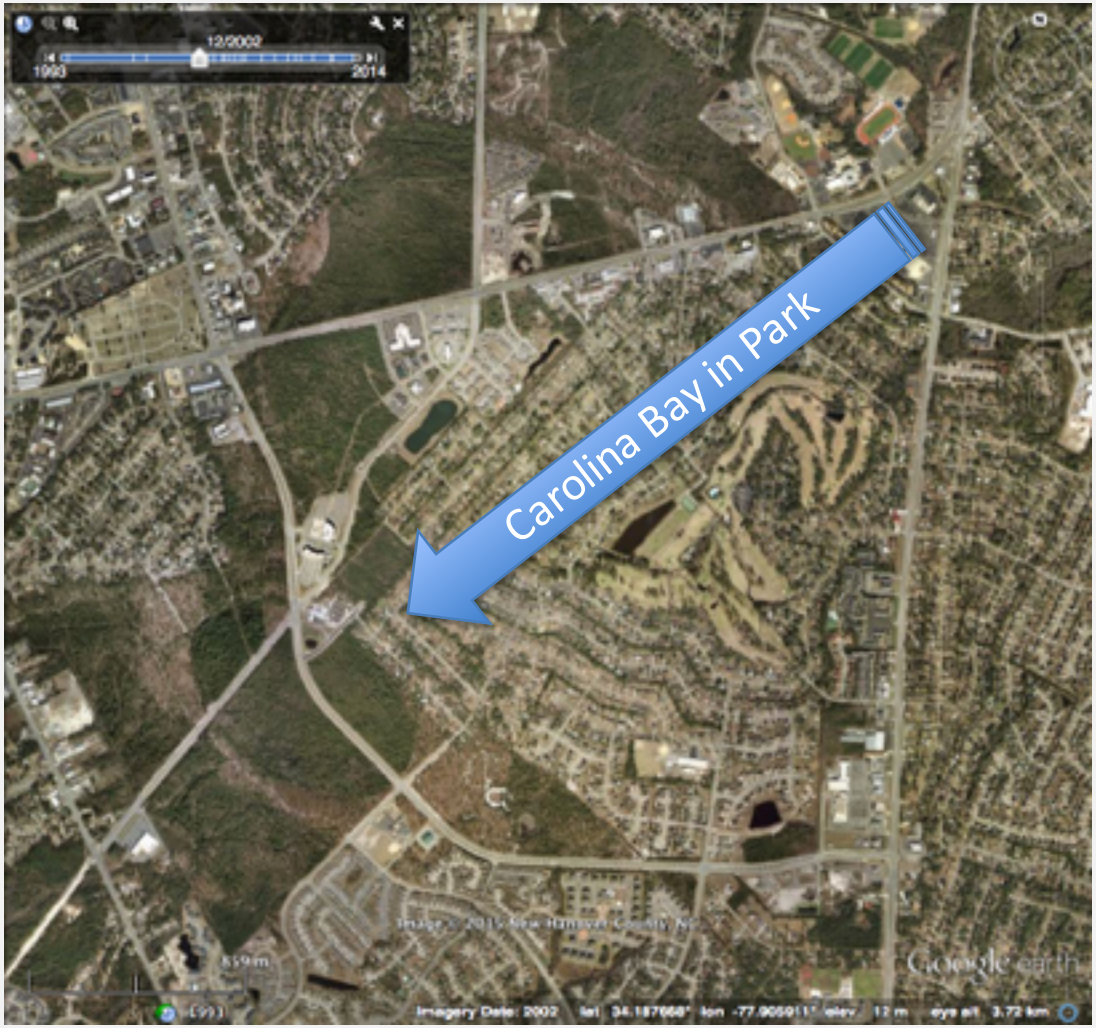


Eyton & Parkhurst, 1975, *A Re-evaluation Of The Extraterrestrial Origin Of The Carolina Bays*

Earlier attempts at triangulation have drawn straight lines on flat maps. The Coriolis force applies at this scale of geophysical mass transport over a rotating, spherical playing field and needs to be considered.

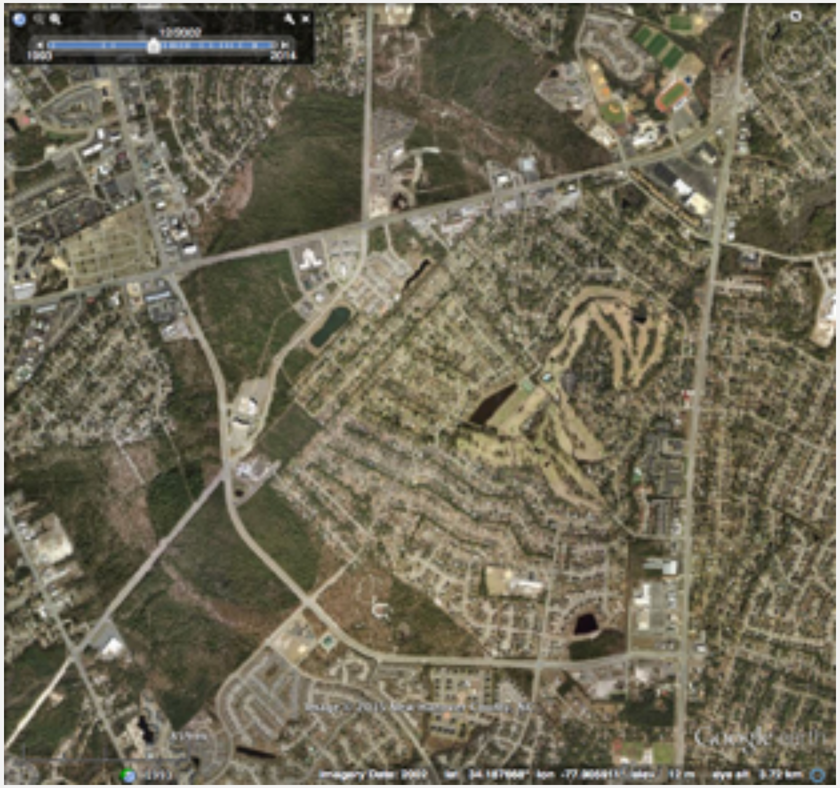
Having accurate measurements of the orientations is also a necessity. So, I developed remote sensing techniques to survey the bays, and have measured 45,000 to date.

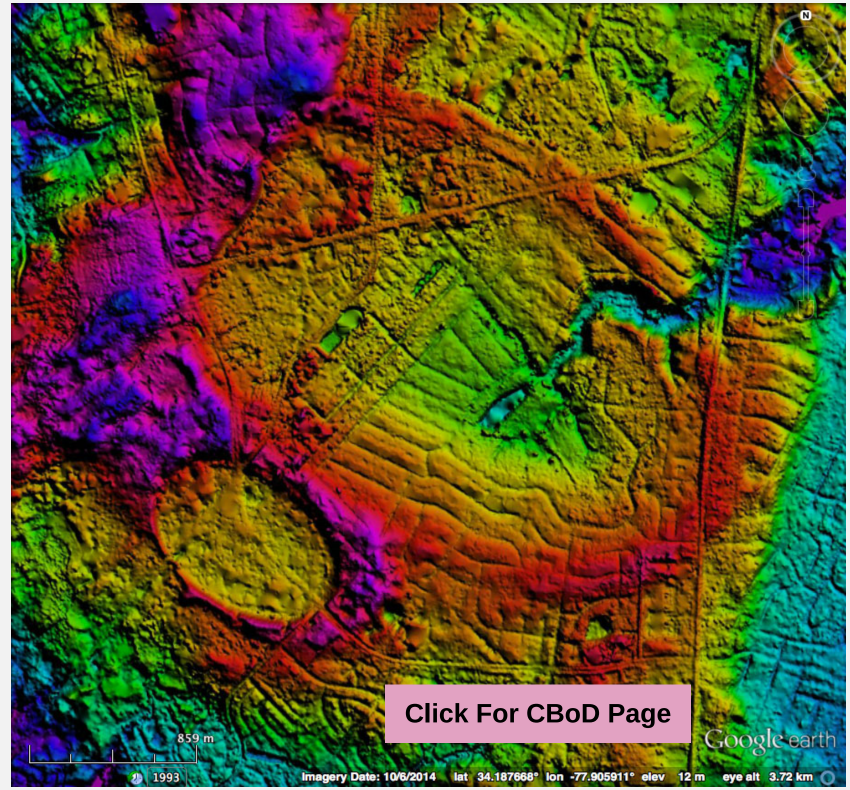
Wilmington, NC's Blythe Bay



But first I had to find them. In this urban landscape, a bay in a park might be noticed –

Wilmington, NC's Blythe Bay



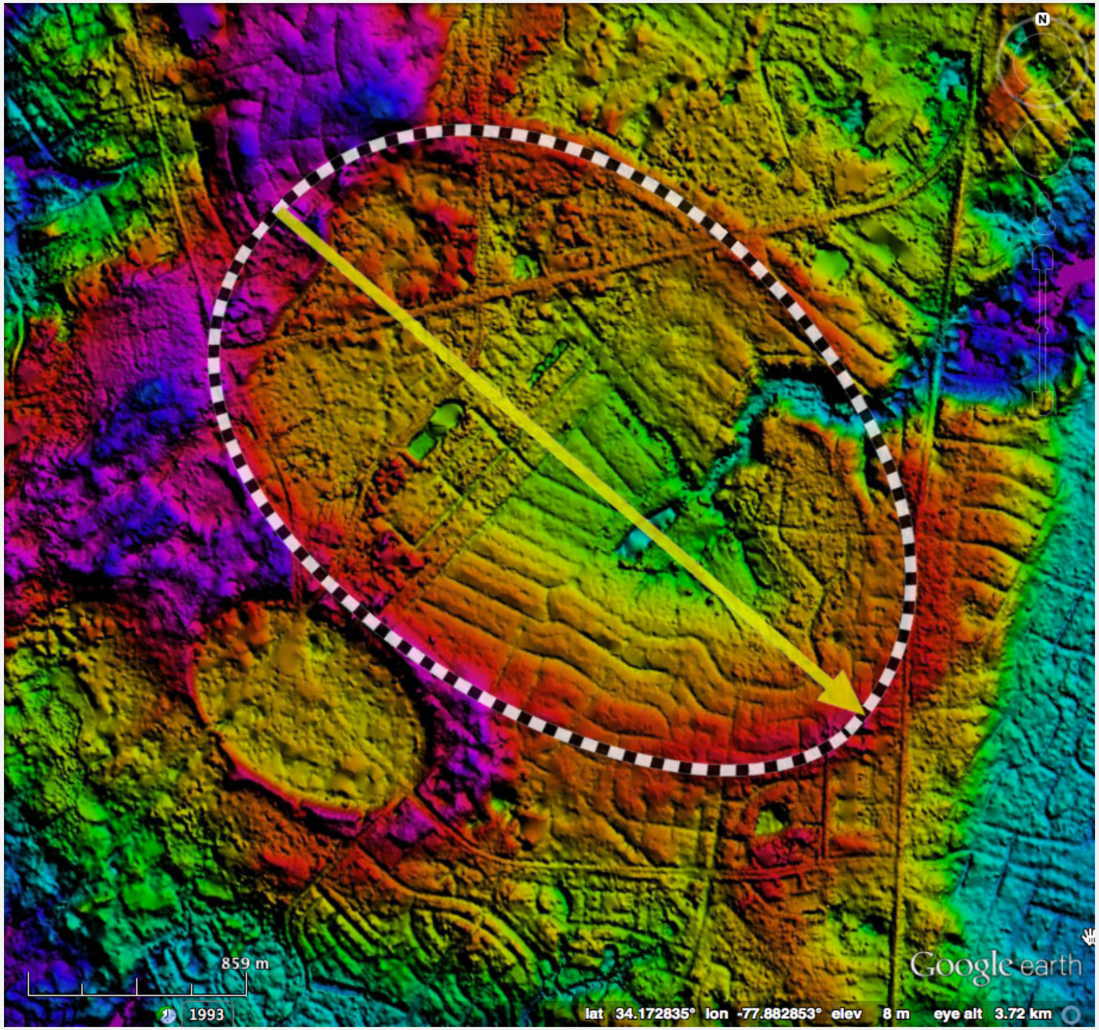


…but that would be overlooking the big elephant in the room: **Blythe Bay**, here rendered using a hue-saturation-value (hsv) LiDAR digital elevation map.

LiDAR reveals that Carolina bays are not "wispy ephemeral" landforms, but instead represent massive structures deeply rooted into the landscape, and robust enough to survive alteration by dunes (entering from upper left), inundation by marine high stands (documented across floor of bay *) and fluvial erosion (evidenced by encroaching headward stream erosion). Not to mention roadways, hospitals, shopping malls, homes and golf courses.

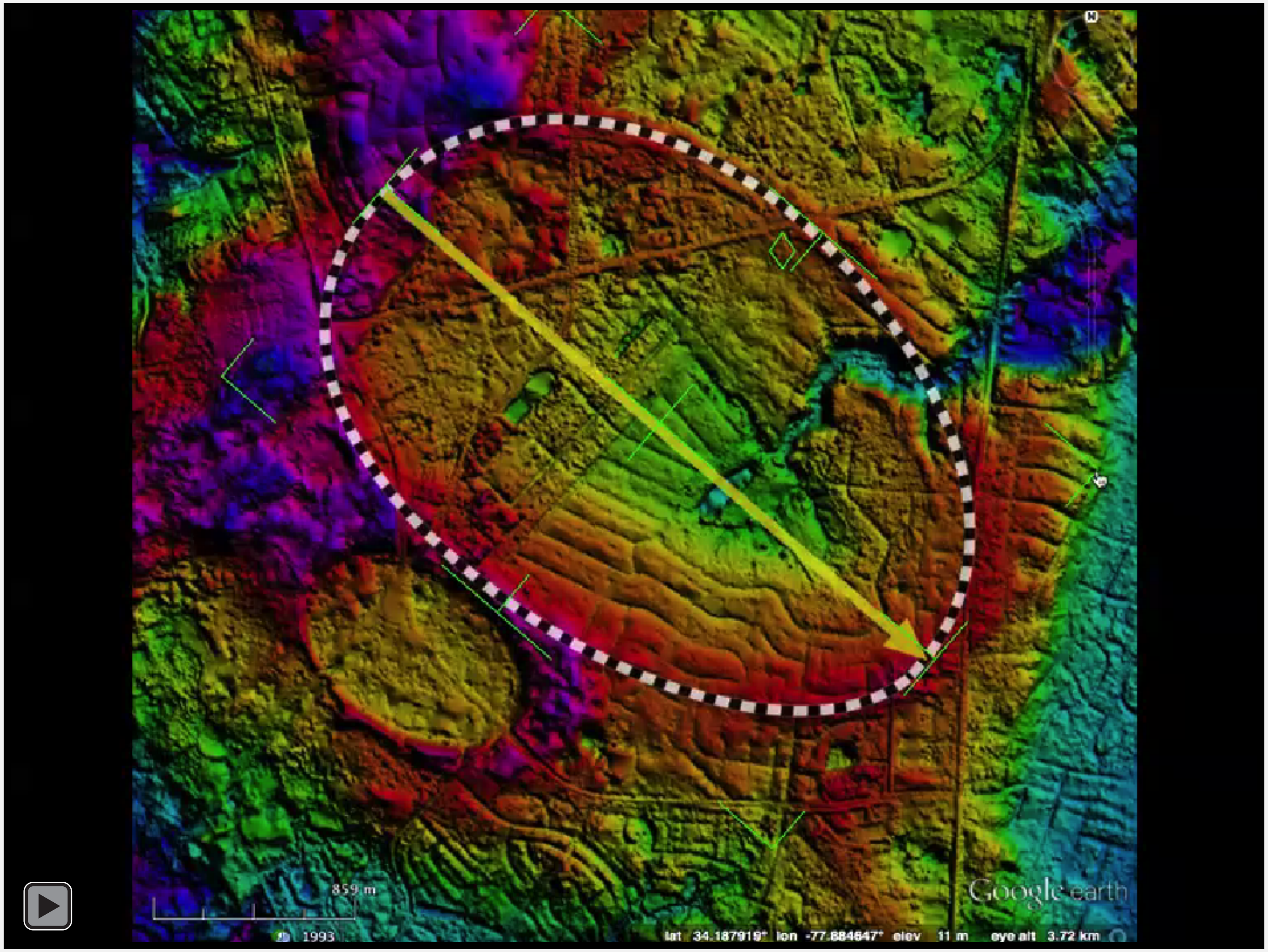
* Wells, 1943

Wilmington, NC's Blythe Bay



To facilitate the survey, I generated LiDAR imagery for much of the East Coast and integrated it into Google Earth. Using an overlay template I traced from an archetype bay, the planforms shape, size and orientation has been measured for 45,000 individual bays.

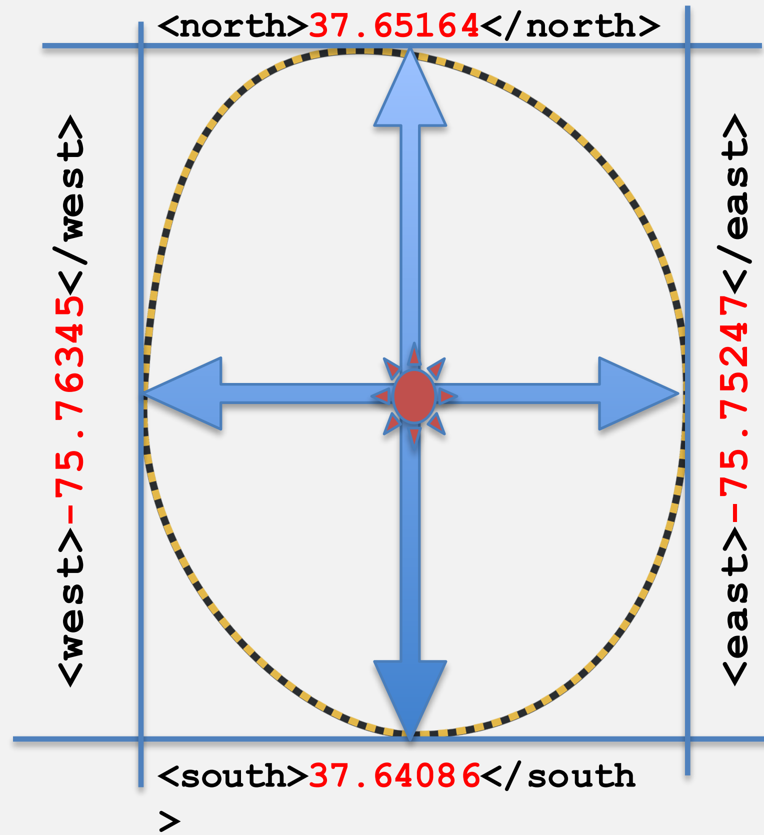
Manipulating Google Earth GroundOverlay Template



By using the rotational and corner handles, it can be adjusted to obtain a satisfactory fit. The smaller bay matches this particular template in an eerily robust manner, as do over 23,000 others in the survey.

Bay Metadata in `GroundOverlay` KML

```
<GroundOverlay>
  <name>136311_7561</name>
  <Icon>
     <href>http://cintos.org/bayCarolina.png</href>
  </Icon>
  <LatLonBox>
      <north>34.18599227212678</north>
      <south>34.17618955111198</south>
      <east>-77.91164005745605</east>
      <west>-77.92007619203626</west>
      <rotation>-135.5020602267536</rotation>
  </LatLonBox>
</GroundOverlay>
```



The Google Earth groundOverlay is documented in metadata. Its **rotation** from due north reports the bay's orientation and the Lat Lon Box coordinates create a bounding box that defines the major and minor axis of the bay. The metadata is run through a program that calculates various metrics, such as a centroid, area and a unique spatially---referenced index name.

http://cintos.org/FusionTables

micintos@gmail.com

Share

Carolina Bay Geospatial Survey

Primary table for all Carolina bay planforms identified in Survey.

Cintos - Edited on February 22, 2015

File Edit Tools Help | Cards 1 | Map of Location | Rows 2 | Chart 1 | Bearing | Planforms | Plot layout

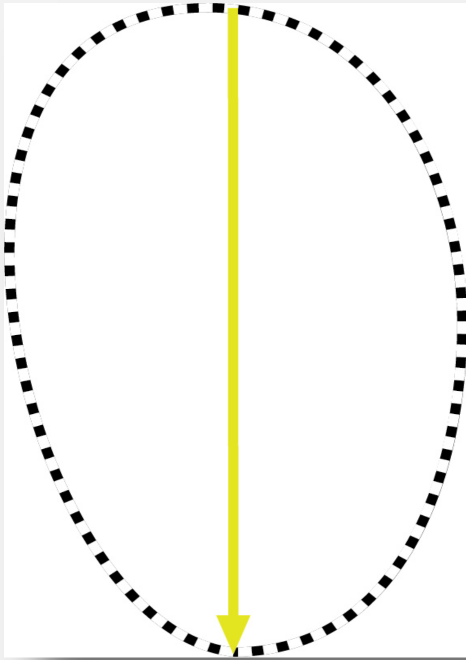
Filter | No filters applied. Sorted by Major | Saved

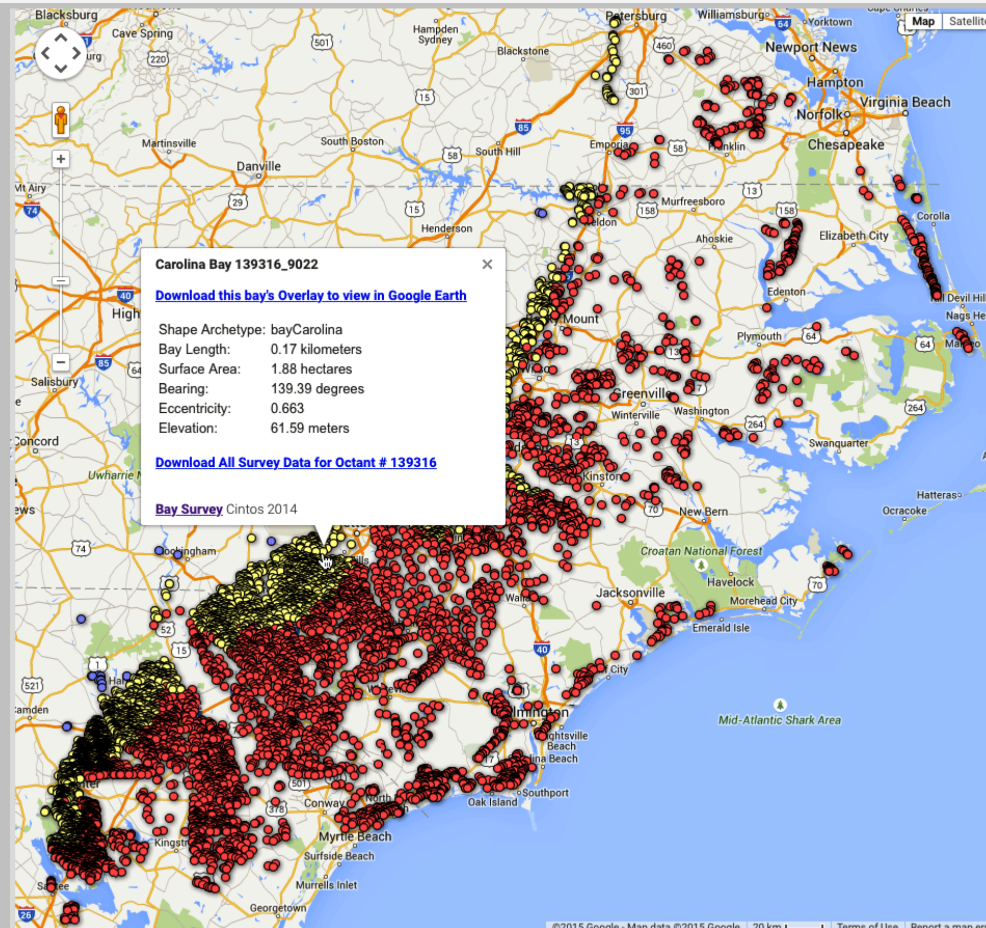
1-100 of 44712

Name	Octant	Location	Latitude	Longitude	Major	Minor	Eccentricity	Area	Bearing	Elevation	Planform	effectiveDiameter
143305_0792	143305	35.76971457755708,-76.4806032656932	35.76971	-76.4806	7.95	6.19	0.627	3869.29	119.85	3.41	bayCarolina	7,018.918
137314_1301	137314	34.2846613788309,-78.50483098044464	34.28466	-78.50483	7.82	5.41	0.721	3327.51	130.04	13.0	bayCarolina	6,508.999
143305_1073	143305	35.776172854237366,-76.4349204750797	35.77617	-76.43492	7.8	5.95	0.647	3649.4	119.85	3.2	bayCarolina	6,816.56
143305_0479	143305	35.76060723792432,-76.44936594858973	35.7606	-76.44936	7.8	5.95	0.647	3650.11	119.85	3.2	bayCarolina	6,817.223
161389_8492	161389	40.46134539791095,-97.48241246284817	40.46134	-97.48241	7.58	4.51	0.803	2688.64	242.21	478.4	bayWest	5,850.876
161389_8493	161389	40.46017046773948,-97.48469584986833	40.46017	-97.48469	7.32	4.62	0.775	2663.52	238.23	478.09	bayWest	5,823.479
144308_3260	144308	36.08214761874756,-77.15107032623982	36.08214	-77.15107	6.48	4.67	0.692	2381.29	130.52	12.62	bayCarolina	5,506.31
143306_2340	143306	35.80915518117612,-76.60216569599005	35.80915	-76.60216	6.3	4.77	0.653	2363.24	128.39	3.64	bayCarolina	5,485.402
124332_0456	124332	31.0116894042953,-83.14053938811244	31.01168	-83.14053	6.22	5.74	0.386	2809.05	163.5	58.02	baySouth	5,980.456
143306_1301	143306	35.784527132866806,-76.50424536516681	35.78452	-76.50424	6.02	4.25	0.708	2014.85	118.22	4.02	bayCarolina	5,064.959
137314_2011	137314	34.300012108788856,-78.5291065692627	34.30001	-78.5291	5.9	3.95	0.742	1832.5	134.94	12.71	bayCarolina	4,830.327
141307_8713	141307	35.46919532255327,-76.78399413733563	35.46919	-76.78399	5.9	3.62	0.789	1678.98	128.53	2.38	bayCarolina	4,623.569
164390_6450	164390	41.16026457894836,-97.62636402139944	41.16026	-97.62636	5.87	3.55	0.796	1638.94	228.12	505.74	bayWest	4,568.105
143304_2999	143304	35.82297698339704,-76.2490701689406	35.82297	-76.24907	5.81	4.37	0.658	1998.89	119.85	0.66	bayCarolina	5,044.859
136317_9283	136317	34.23105015897139,-79.45777518149355	34.23105	-79.45777	5.75	4.04	0.711	1828.64	148.21	19.46	bayCarolina	4,825.237

The results are then loaded, one row per bay, into a Google Fusion Table that is publicly accessible – just Google the term "Carolina Bay Fusion Table"

Territory of bayCarolina species

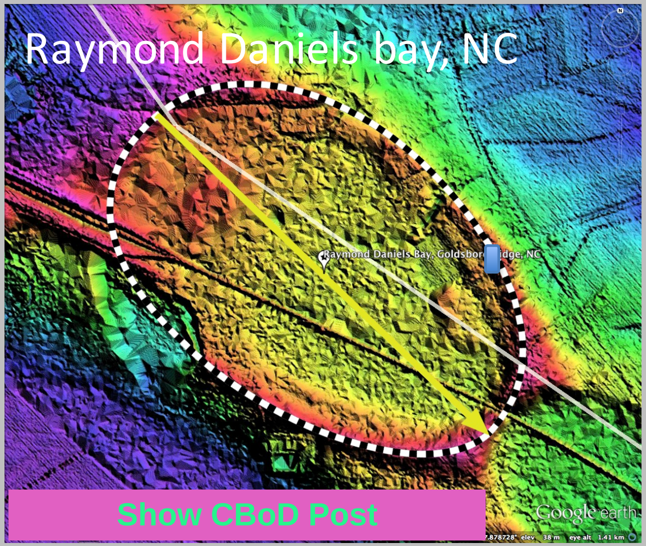


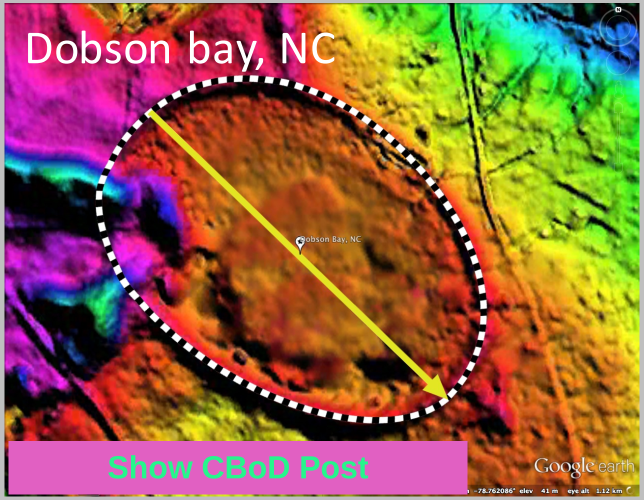


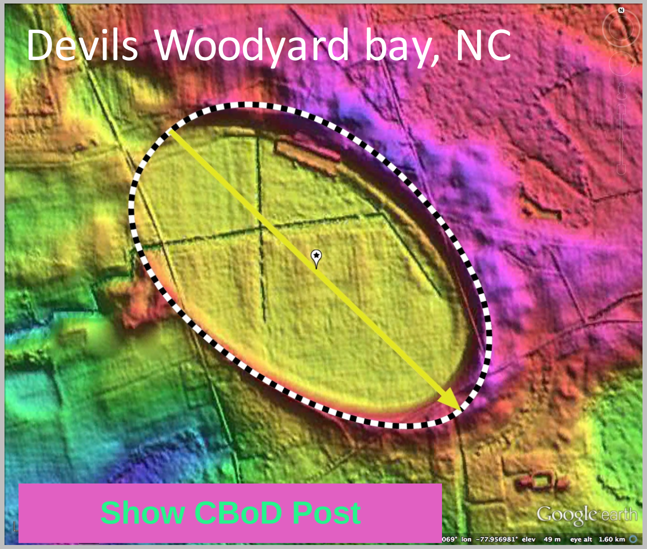
Click to View Live Map

Here is a Fusion map showing the spatial extent of what I have named the bayCarolina type. Each bay has a placemark for inspection of its metrics. Note that the archetype template is a pure oval on one side, but slightly flattened on the other. Although subtle, these nuances in the bay planform are found to be robustly evident in the LiDAR.

bayCarolina Species

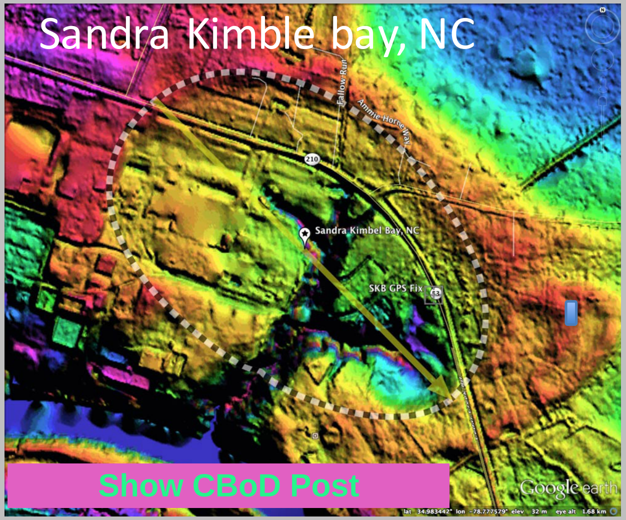


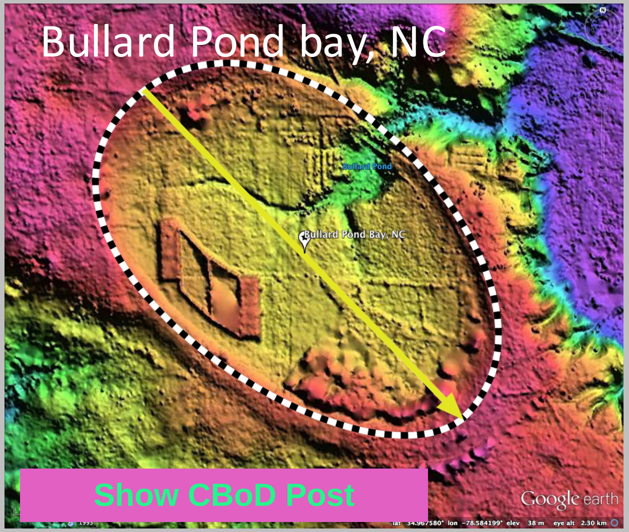


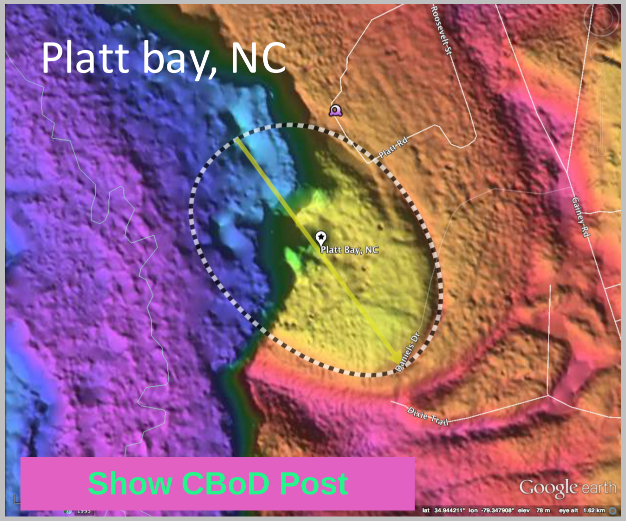


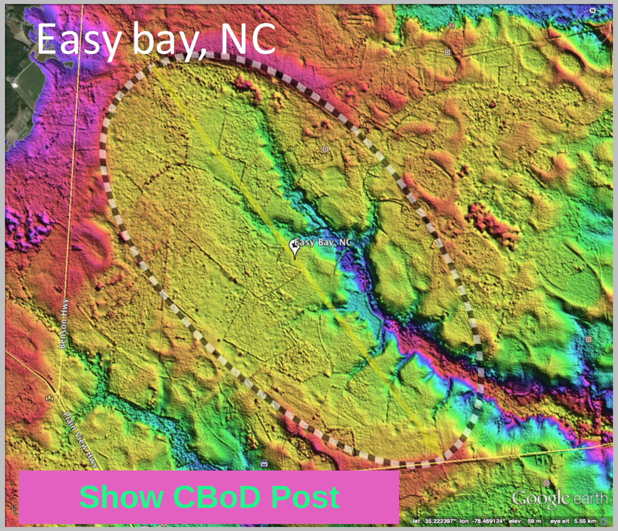
These examples of the bayCarolina type are easy to recognize even in aerial photography.

Heavily Eroded bayCarolina Species



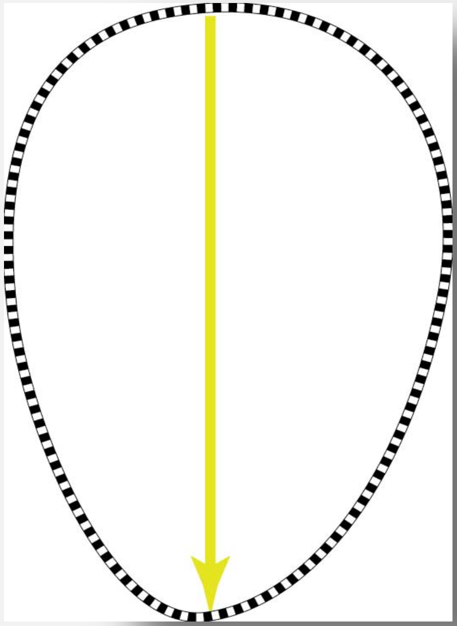


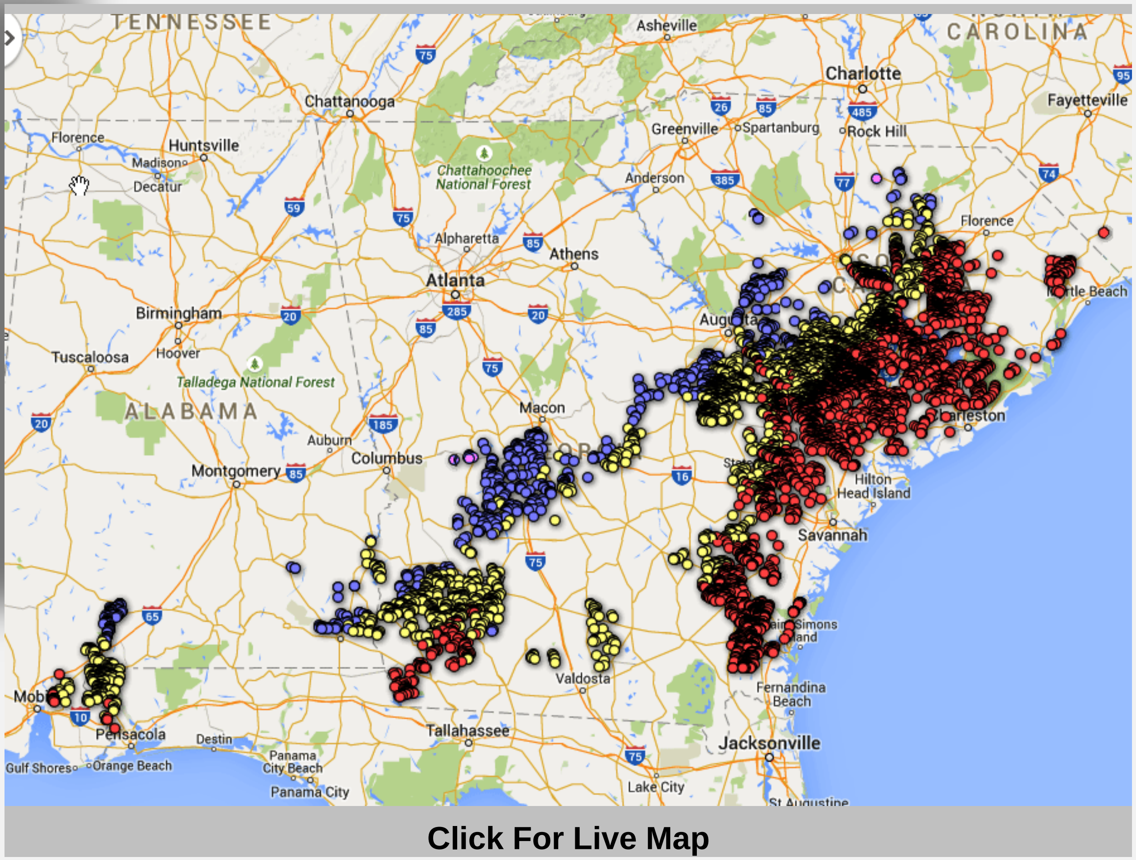




In many instances, the bays have been compromised and are only apparent in the LiDAR.

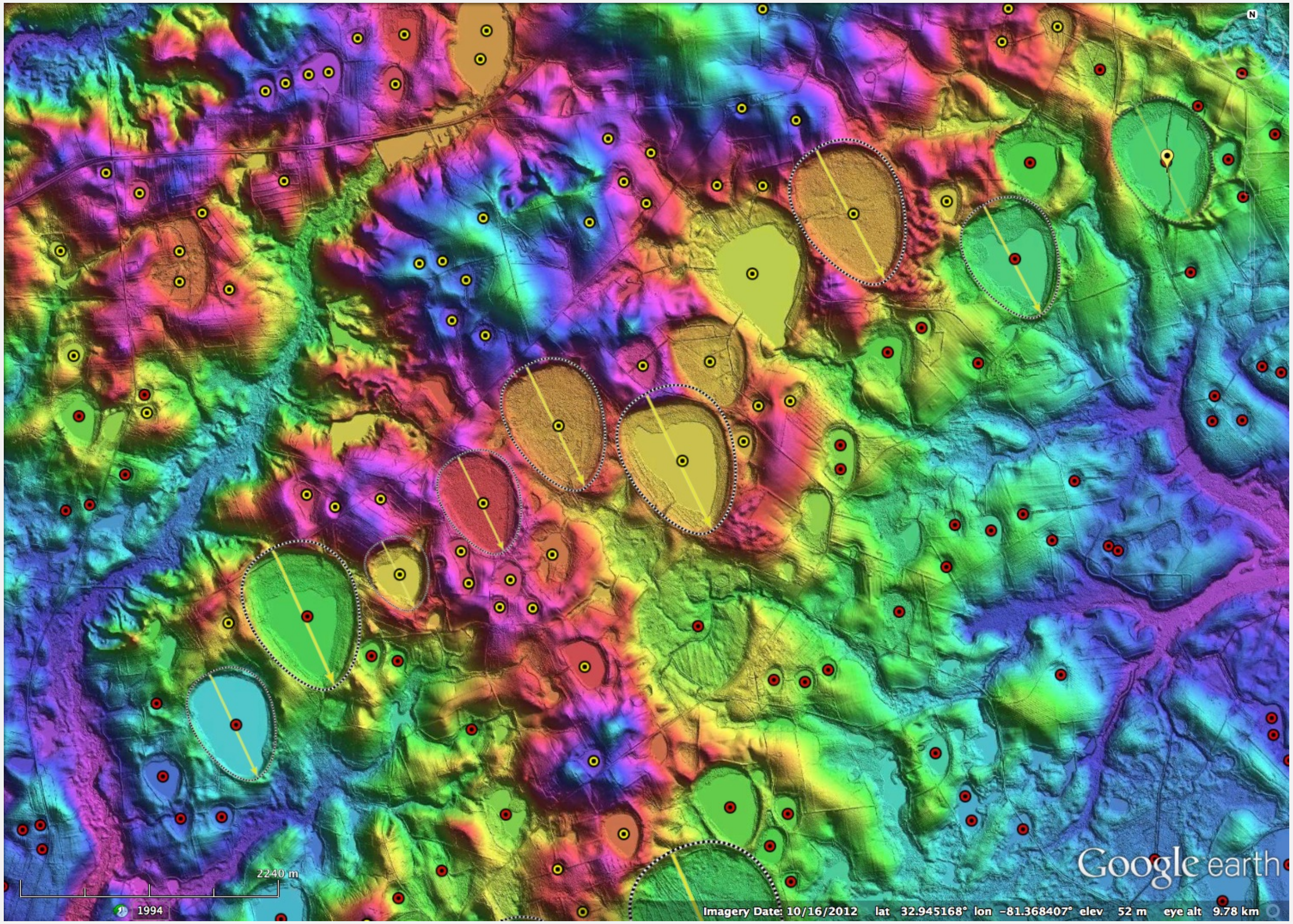
Territory of baySouth species





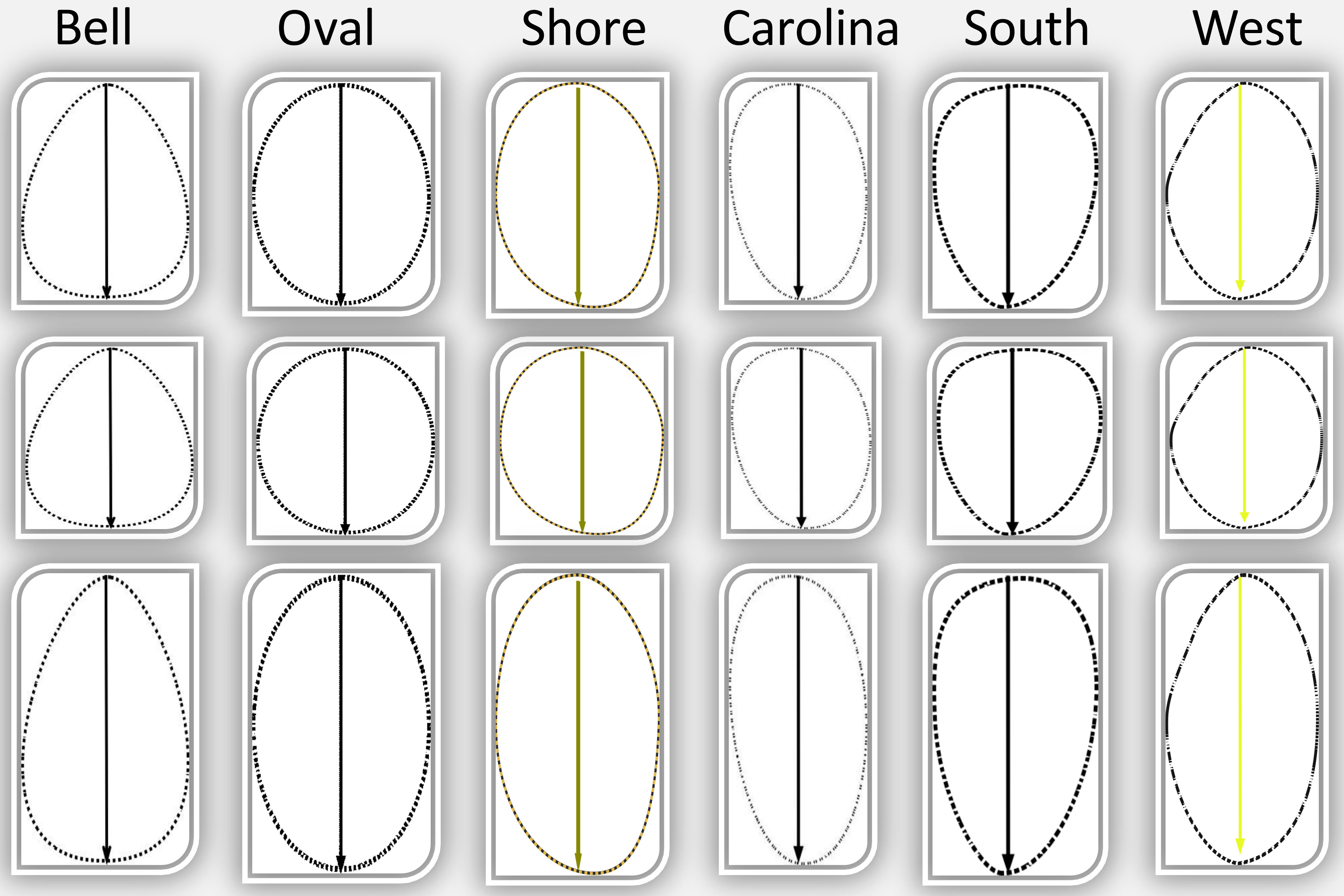
The baySouth is the second most numerous archetype.–It has a more pointed SE end.

baySouth Examples



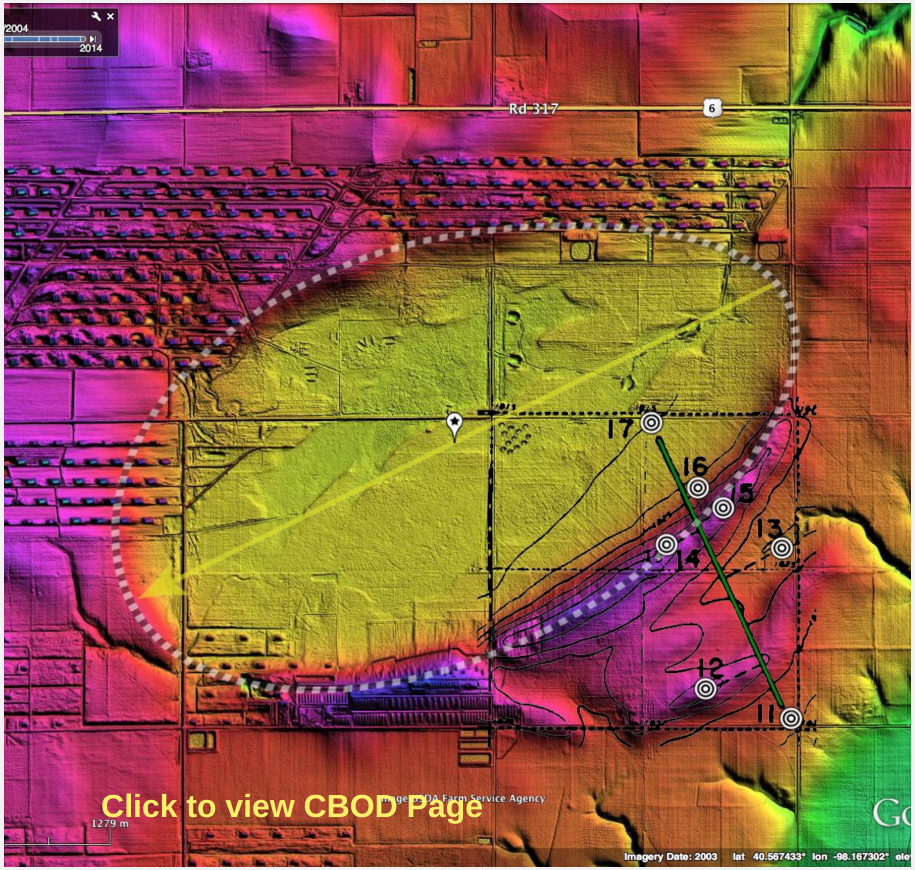
Here are some “baySouth” Examples. Note that the elevation of the bay has no control over the shape or orientation.

Six tightly constrained archetypes



Six unique shapes have been identified, representing subtle variations of an ovoid shape that can be foreshortened or stretched to match the eccentricity evident in the LiDAR. Note the “bayWest”.

McMurtrey Marsh Rainwater Basin

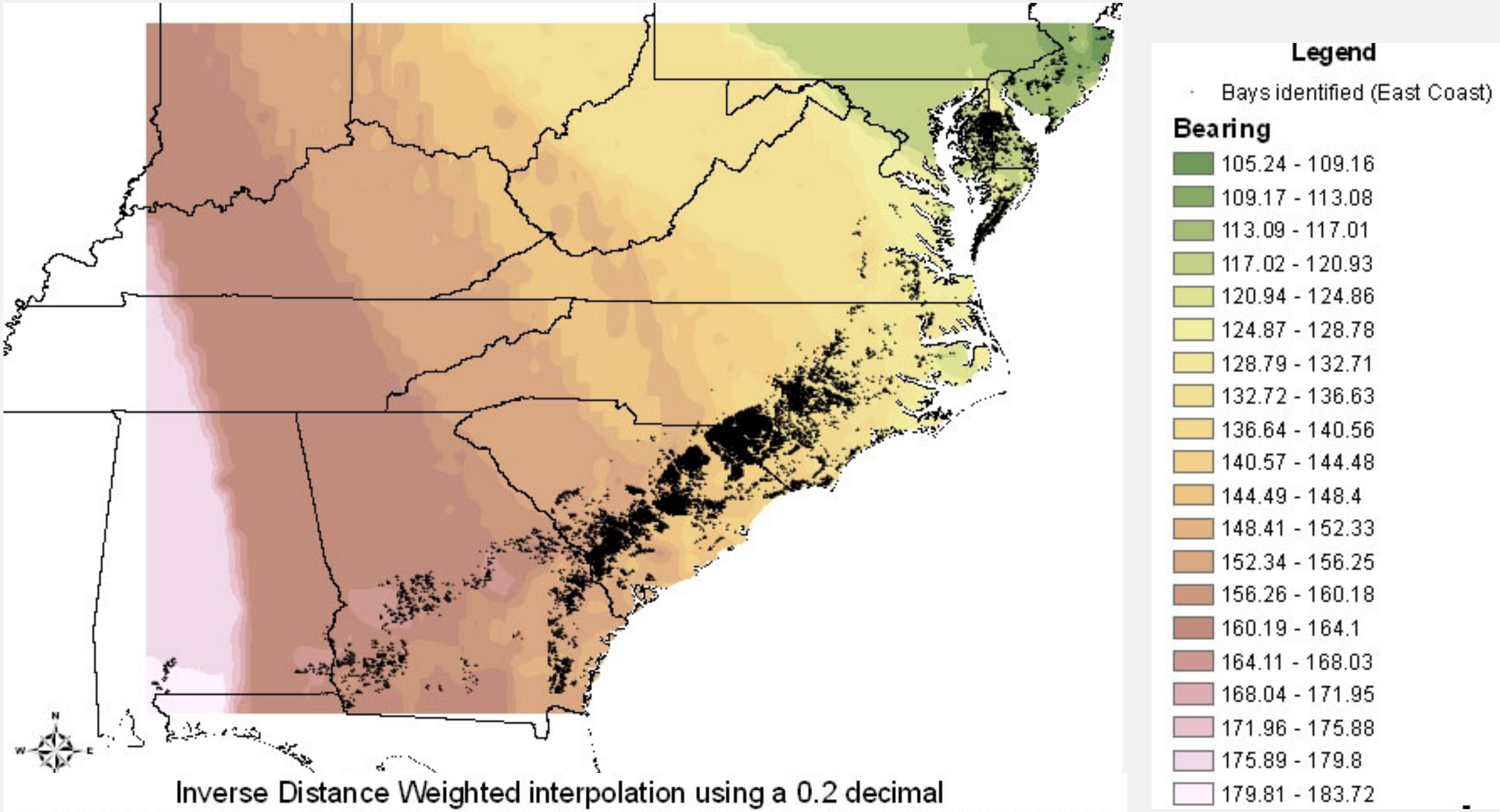


The "bayWest" matches the planform of Nebraska's Rainwater Basins, …which don't look like much …until viewed in the LiDAR.

Kuzila found these to be crisp ovoid depressions in antecedent terrain projecting up through tens of meters of late--Pleistocene loess; Zanner noted a striking similarity to Carolina bays.

Mark S. Kuzila, 1994, *Inherited Morphologies of Two Large Basins, Clay County, Nebraska, Great Plains Research, Paper 155.*

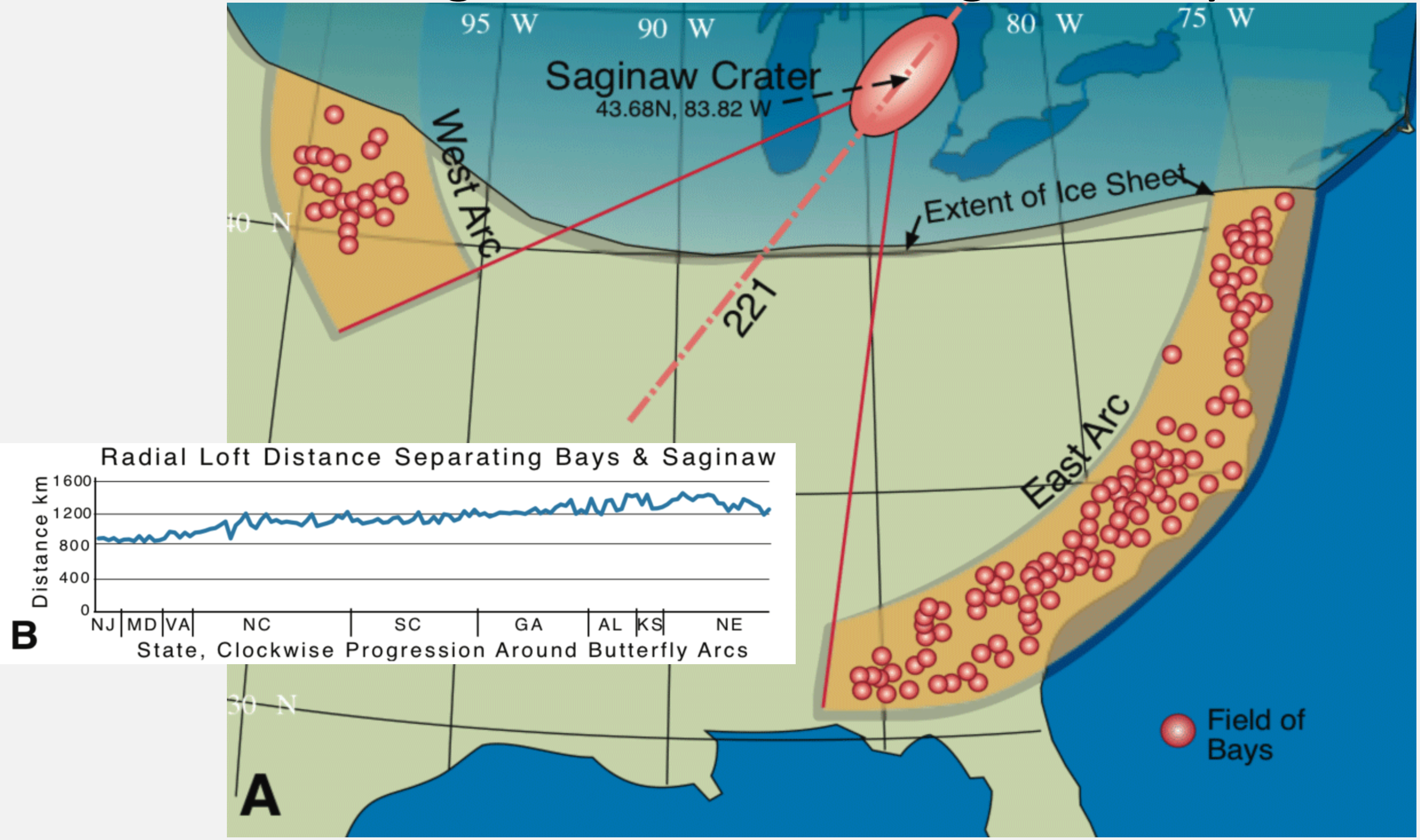
Clockwise Rotation of ~75º from NJ through Alabama



Inverse Distance Weighted interpolation using a 0.2 decimal degree search radius, minimum 3 points, and output grid size of 0.2 decimal degrees.

One of the primary rationales for executing the Survey was to obtain high--resolution data on the orientation of the bays, and this IDW map documents them rotating ~75 degrees clockwise from New Jersey down to Alabama.

Triangulation Locus – Saginaw Bay, MI



I have been proposing this triangulation since 2010. The bays are neatly aligned along an annulus centered on Saginaw Bay, split into two “butterfly wings” reflecting from a proposed 222º impactor arrival azimuth, a common signature of oblique cosmic impacts. Note the consistency of the geographic distances at which the bays are located from Saginaw Bay.

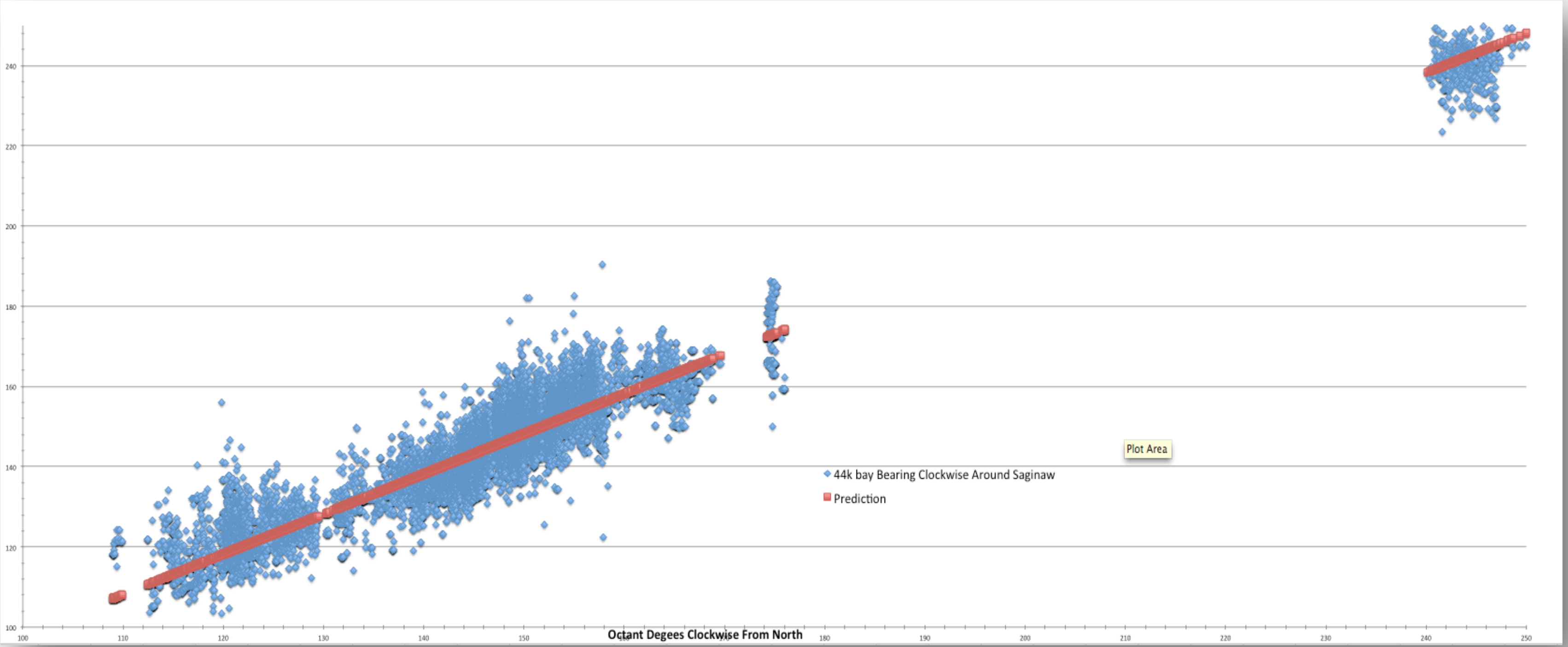
An Illinoisan continental ice sheet is proposed at the time of impact, truncating the annuls to the north, where the ejecta debris would land on top of the ice sheet.

Predicting Orientations

The orientation of a given bay can be predicted using simple Trig. The aviation bearing from Carolina bay **A** towards the Saginaw epicenter **B** is computed, with a Coriolis adjustment applied.

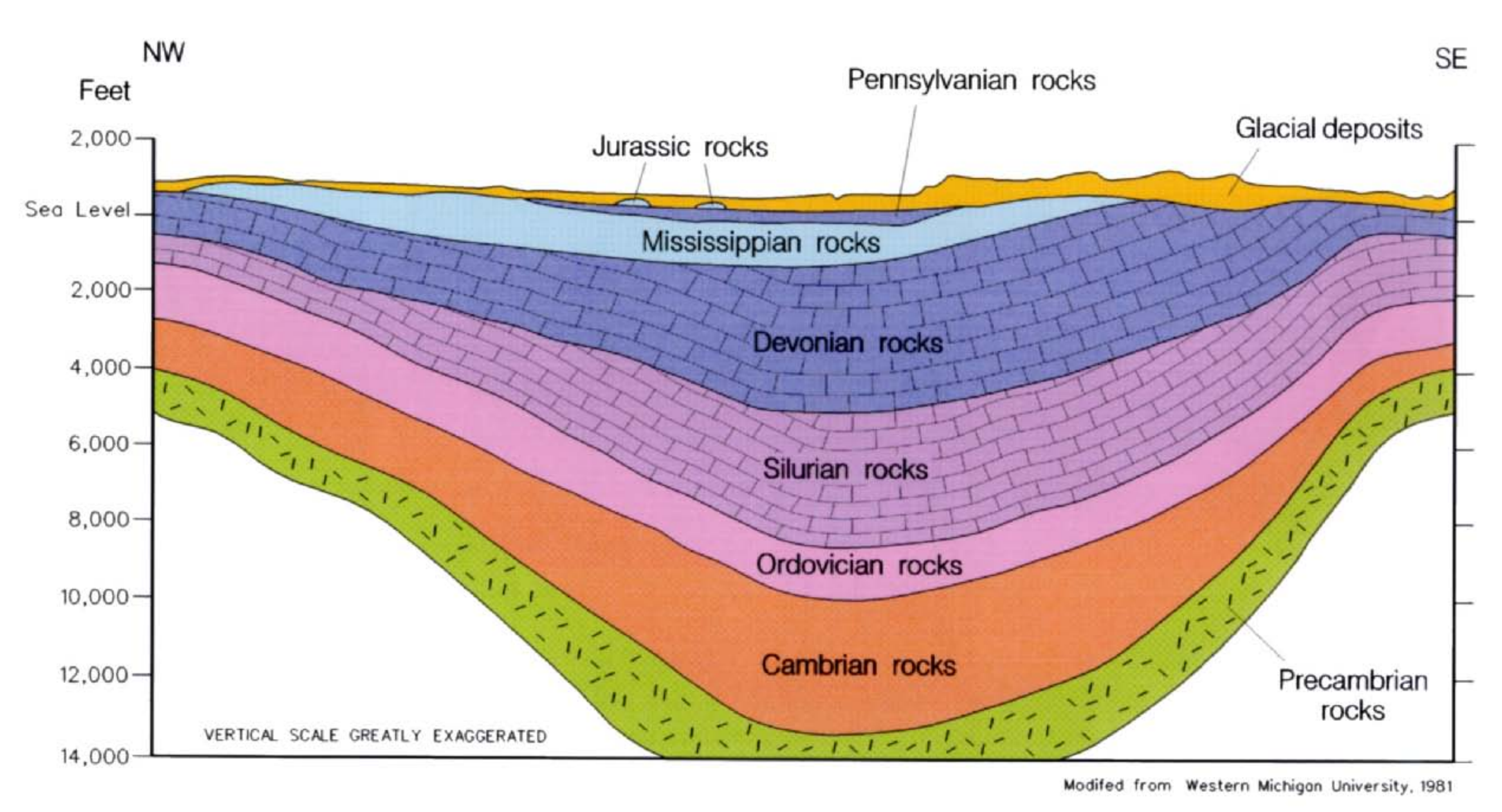
Great Circle Bearing @ A =

```
180+(ATAN2(COS(latA)*SIN(latB)-
SIN(latA)*COS(latB)  *COS(lonB-lonA),  SIN(lonB-
lonA)*COS(latB))*180/PI())
```



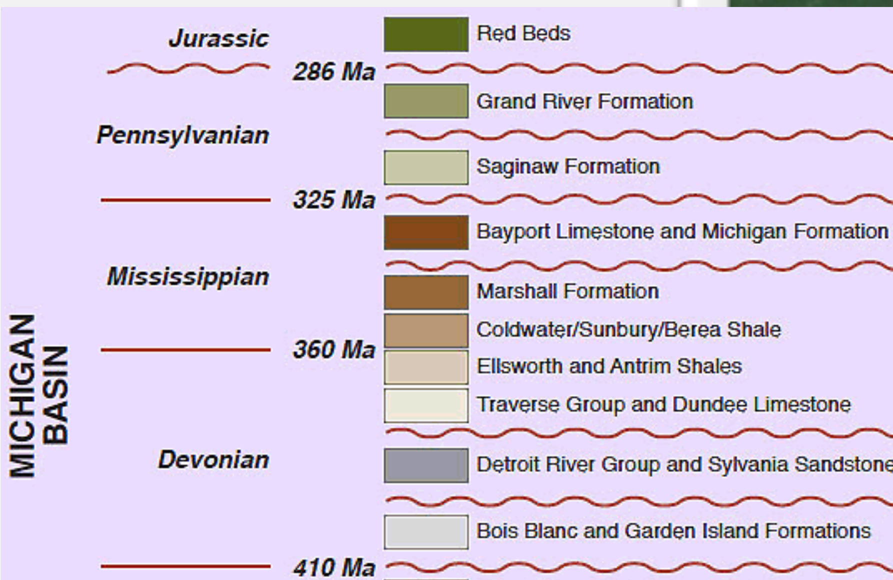
The blue dots in this graph represent the measured orientation of 45,000 bays. The red line shows the calculated orientation for those bay locations. The basins in Nebraska fit nicely into the trend. The formula's **only** input variable is the bay's latitude and longitude.

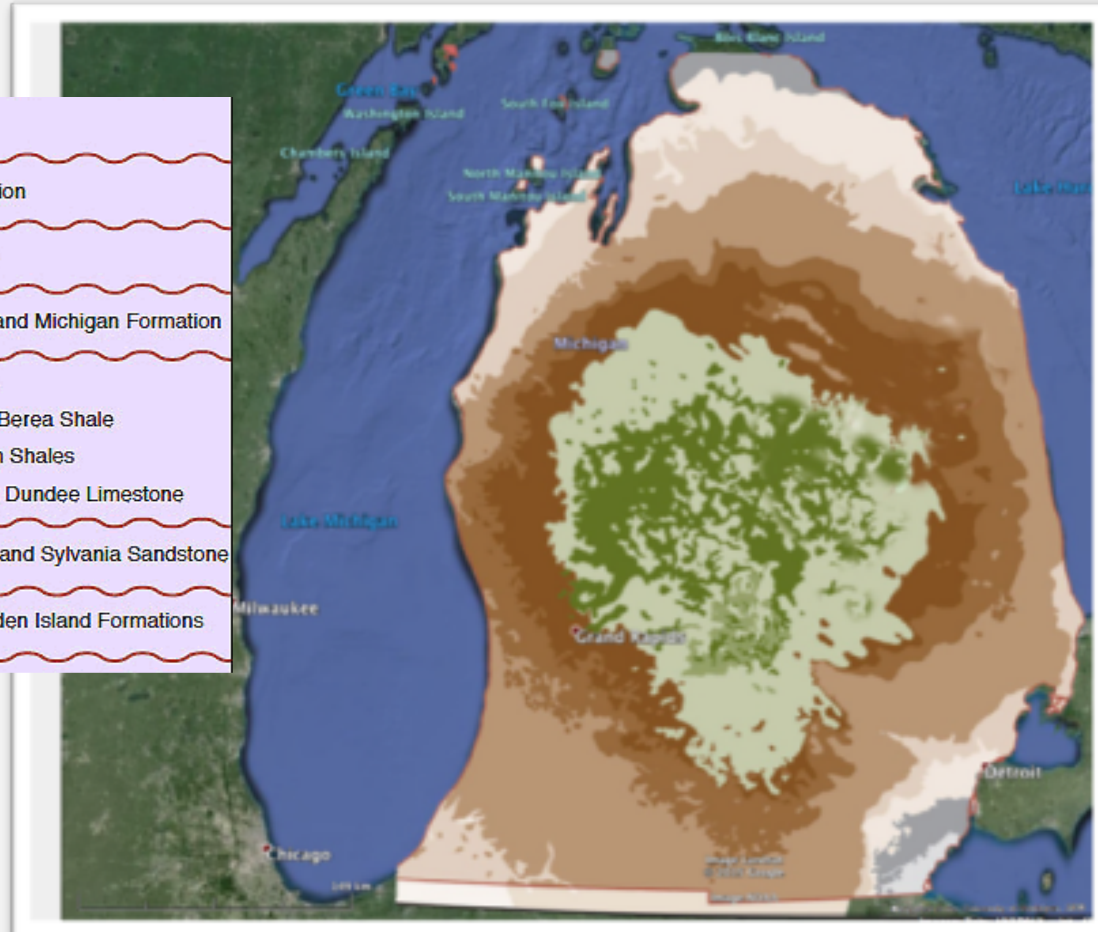
Michigan Basin



So I've been alluding to Saginaw Bay. Let me be clear: I am NOT suggesting the Michigan basin itself is a crater. It was created by infilling sediments as the basin down--warped over hundreds of millions of years. It is currently capped by Jurassic rocks and surficial glacial till.

Central Michigan Basin Strata s   Modified



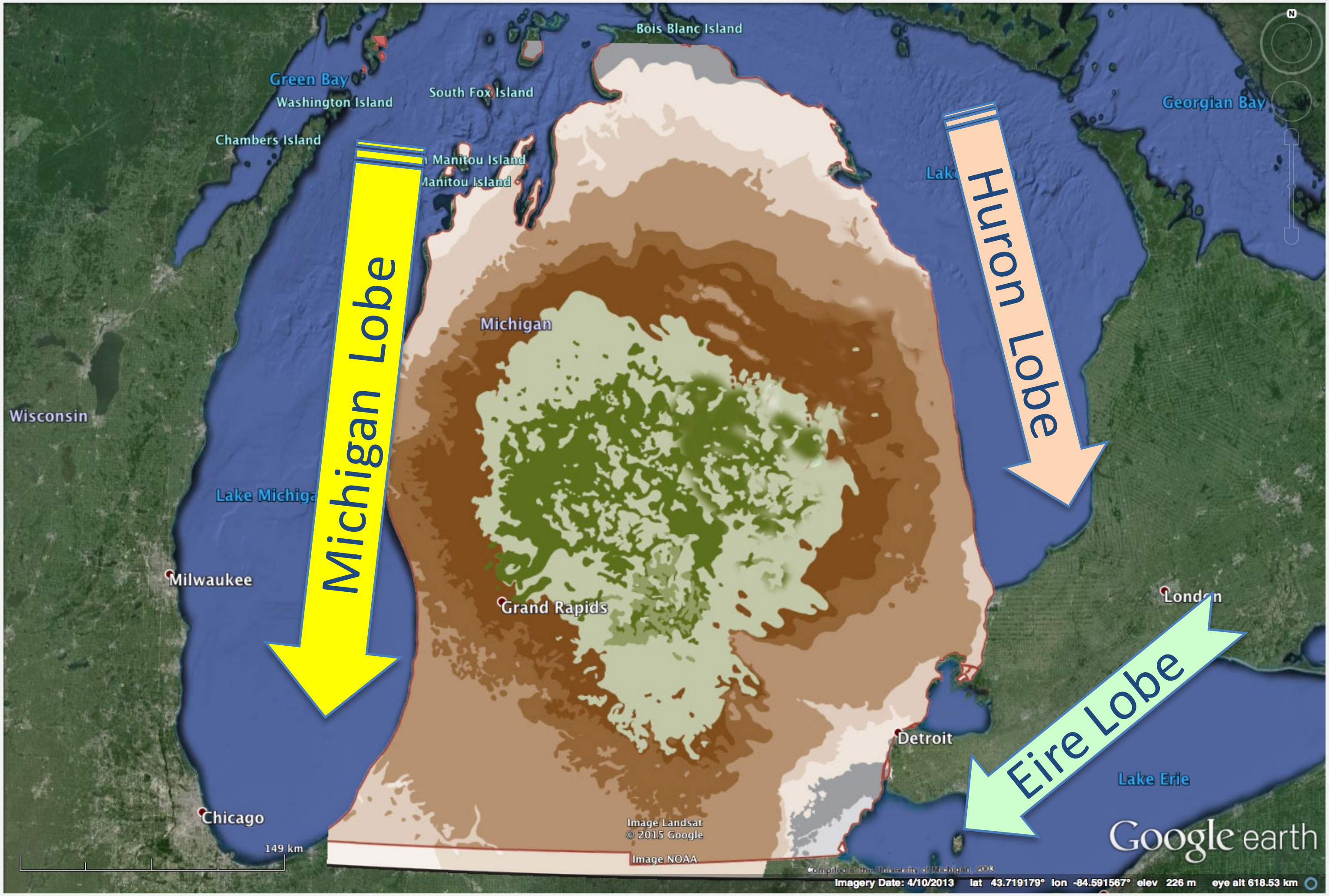


Modified from Cross, Michigan State University, with apologies.

I've modified CROSS's basin map to show the strata at the center of the Michigan Basin as it was originally assembled.

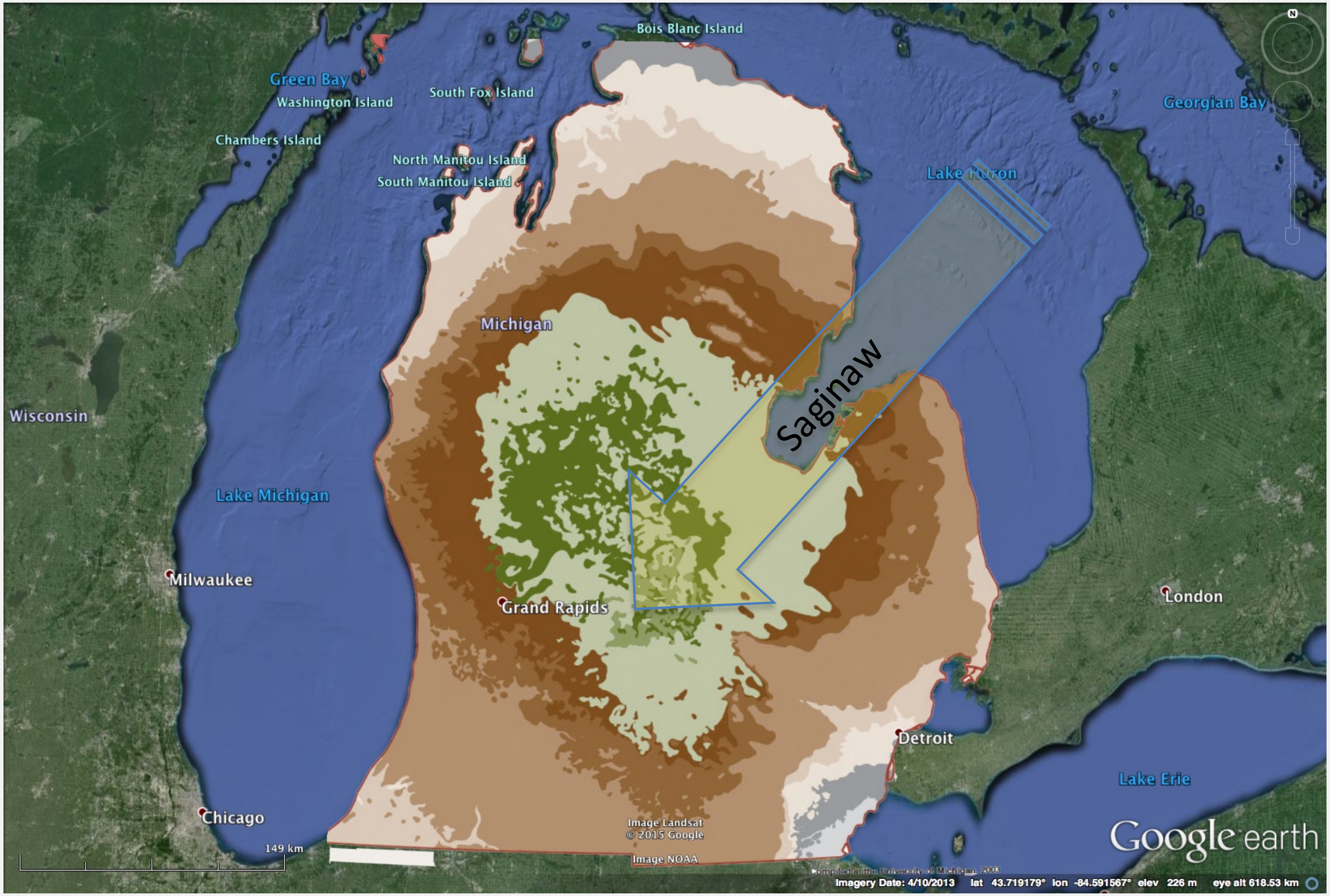
The splattering of sandstone in the center is known as the "Michigan **Jurassic** Red Beds". While considered to have once been more extensive, they are currently seen primarily in valley deposits within the Pennsylvanian strata.

Laurentide Ice Flows



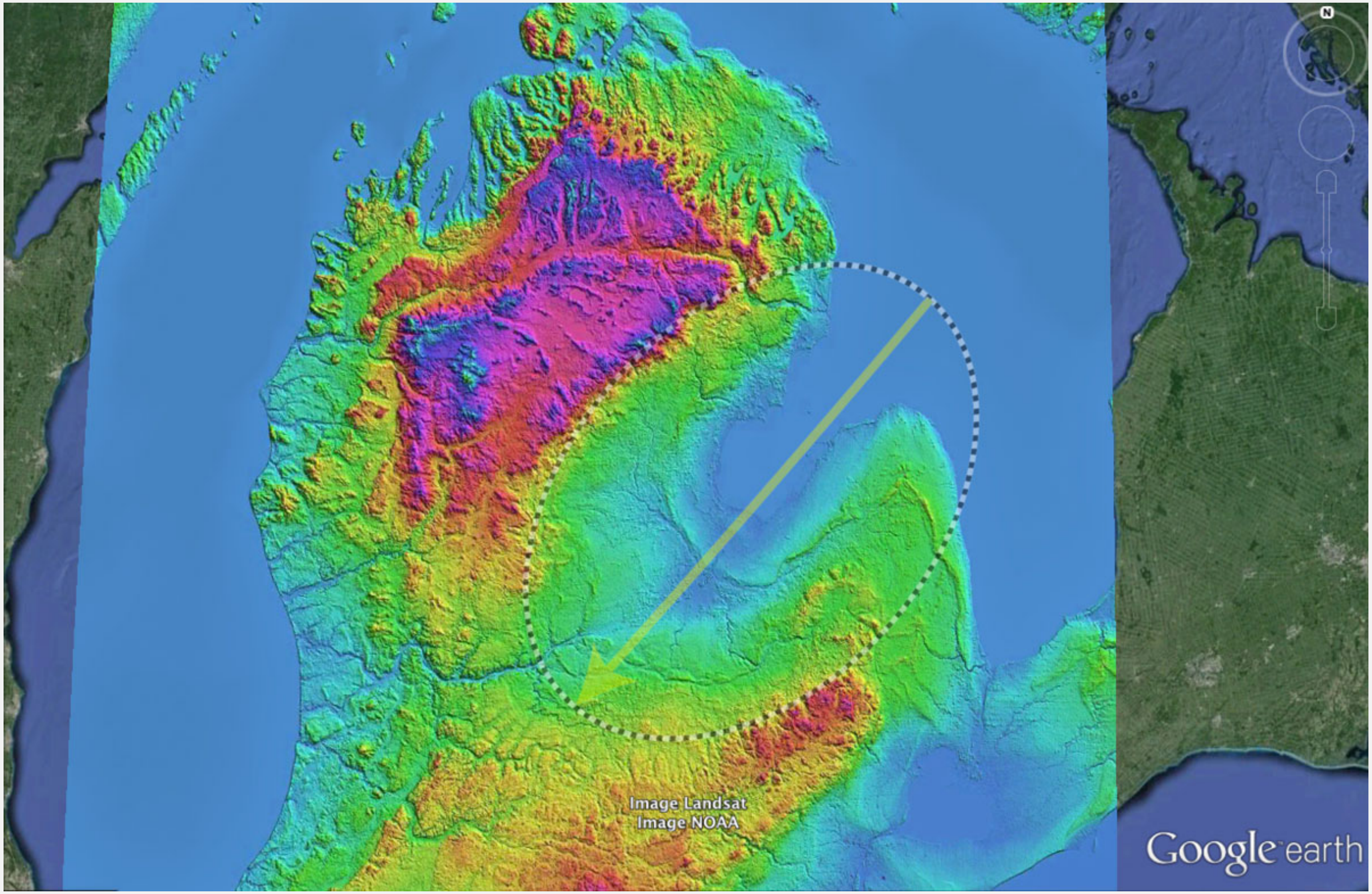
It is generally accepted that the Lake Michigan Glacial lobe passed west of the basin's central structure while eroding older, softer shales. Similarly, the Huron and Erie lobes passed to the east and south. The harder Mississippian and Pennsylvanian deposits resisted that erosion.

Michigan’s Thumb



But Michigan actually has a Thumb. It represents a **unique, singular event** that cuts through the central bedrock, commonly attributed to the erosive actions of the Saginaw Glacial lobe penetrating through the Mississippian and Pennsylvanian Cuestas.

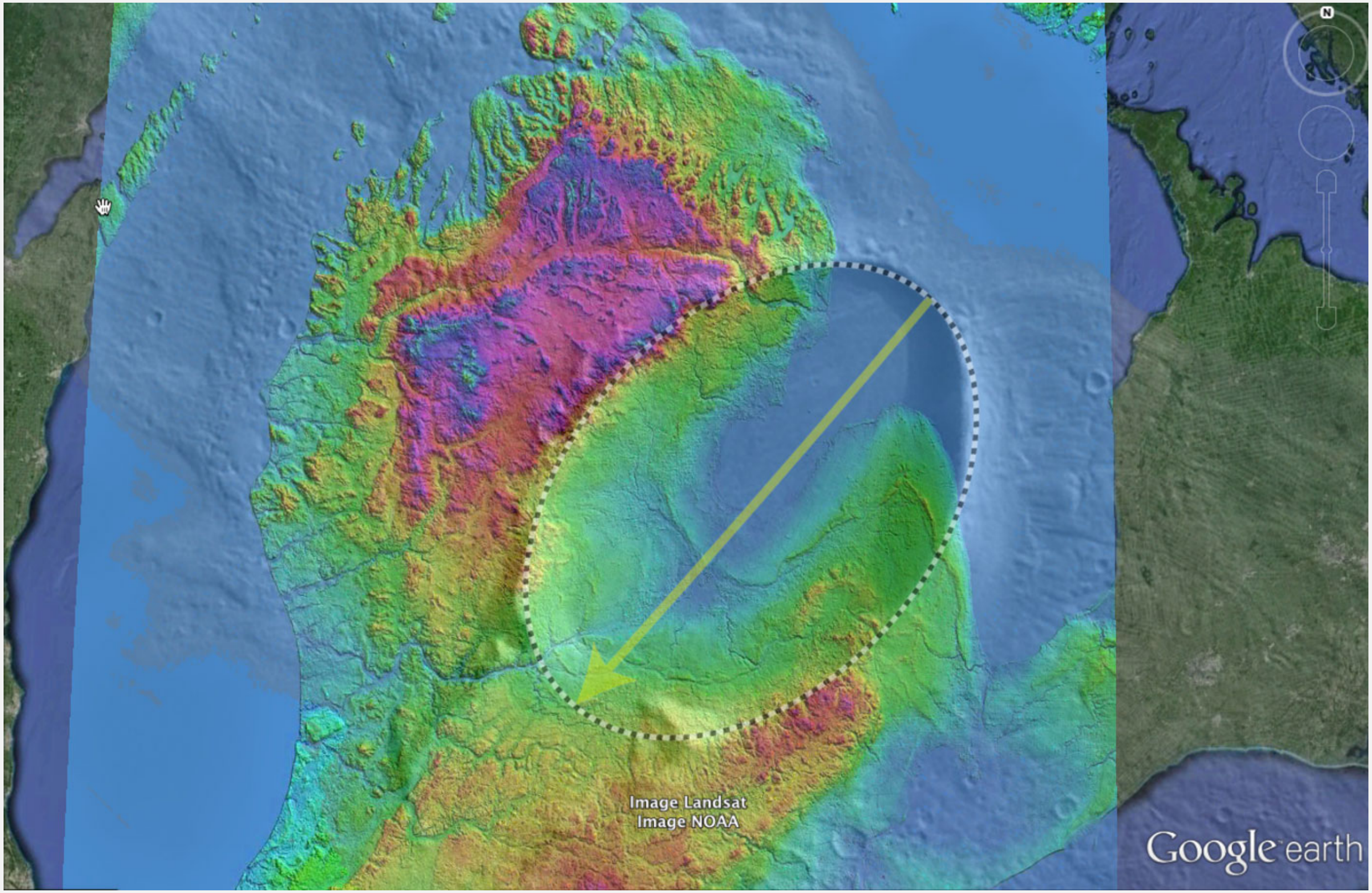
Michigan LP hsv shaded Elevation Map



Here is the Lower Peninsula’s topography in a digital elevation map.

The Saginaw “lobe” can be roughly described by an elongated oval 150 by 300 km, oriented at 222º rotation from North.

Michigan LP hsv shaded Elevation Map



Instead of glacial erosion, we propose this as the footprint of an oblique impact arriving on an azimuth of 222º.

As a conceit, shown here is an oblique impact structure from Mars, superimposed on the digital elevation map.

Marshall Sandstone likely a hydrous target

Hydrous targets react differently during impact events. Additional explosive force & higher ejecta velocities, larger but shallower craters.

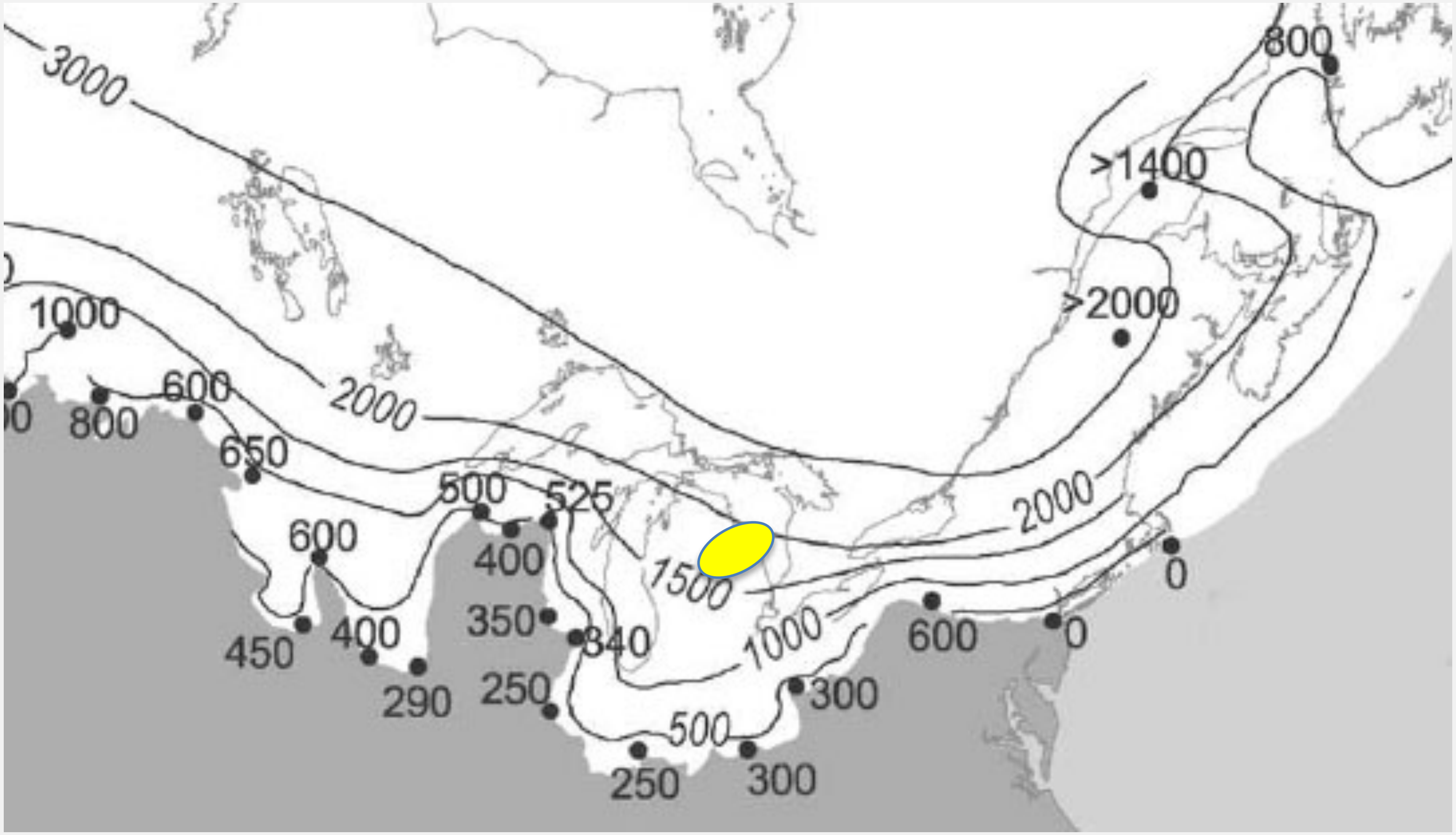
The aquifers of the Michigan basin would present a very hydrated target.

“Cratering efficiency, ***ejection velocities****, and spall volume are enhanced if the* ***pore space of the sandstone is filled with water****. In addition, the crater morphologies differ substantially from wet to dry targets, i.e.,* ***craters in wet targets are larger, but shallower.”***

“We suggest that in addition to strengthC weakening due to the presence of fluids, vaporization of water upon pressure release provides an ***additional explosive potential*** *that superimposes the impactC induced flow field.”*

Thomas KENKMANN, et al, 2011, *Impact cratering in sandstone: The MEMIN pilot study on the effect of pore water, Meteoritics & Planetary Science 46, #6*

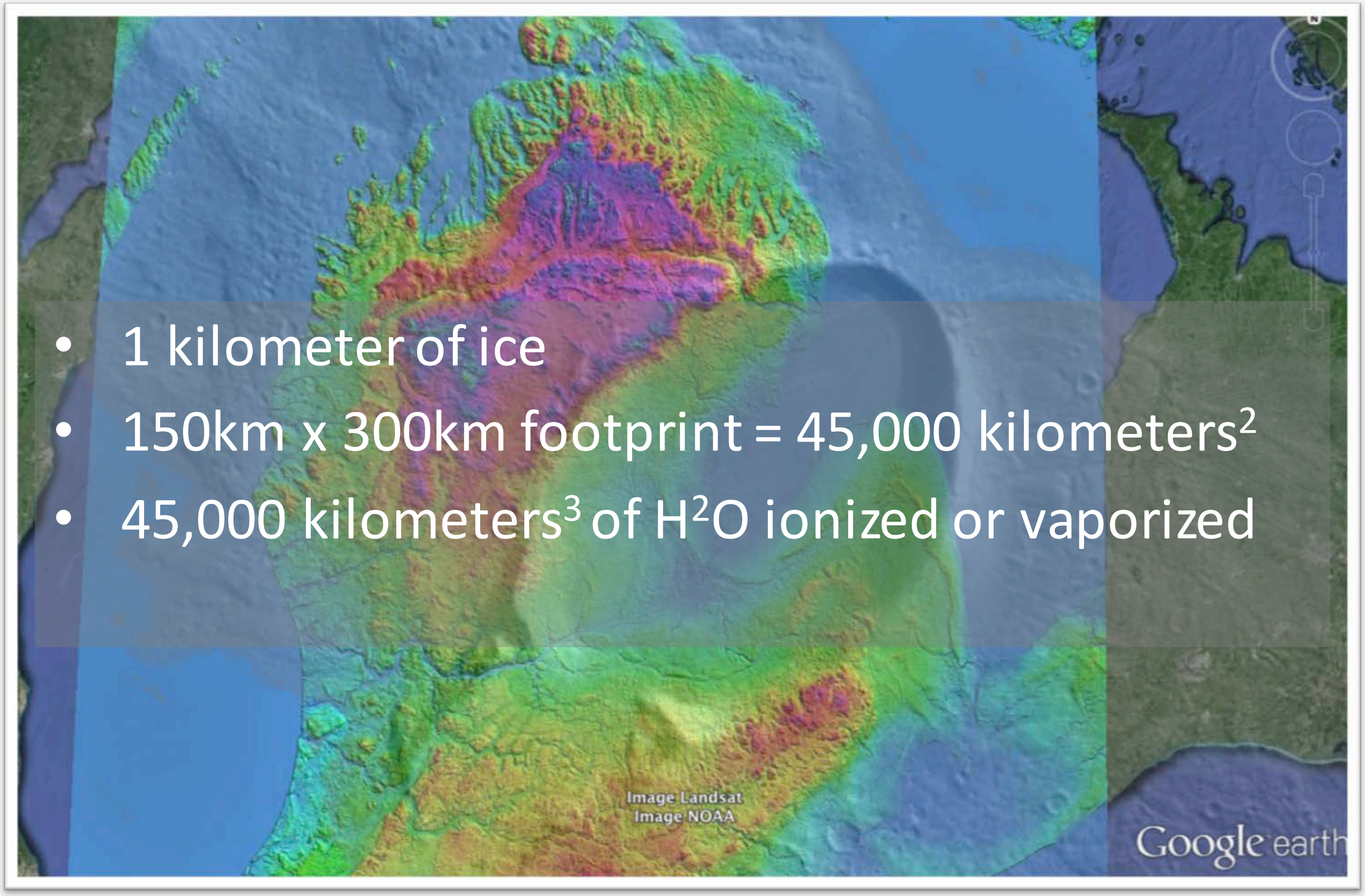
Laurentide Ice Sheet Elevations



For an even more hydrous target, we propose an impact during a Laurentide glaciation, where as much as 2 kilometers of ice may have blanketed the Lower Peninsula. Stickle demonstrated how oblique impacts into ice sheets could result in “Lost Impacts" *, as vertical shock transitions to horizontal shear and subsurface damage differs from classic impact structural markers.

*-Stickle, A. M., and P. H. Schultz (2012), Subsurface damage from oblique impacts into low-- impedance layers, J. Geophys. Res., 117, E07006, doi:10.1029/2011JE004043.

Saginaw Impact Prototype



Given 1 kilometer of ice over this footprint, 45,000 cubic kilometers of water would have been instantly ionized or vaporized. We interpret the distribution of comminuted quartz grains found in the Carolina bay blanket as being ejected out of the Lower Peninsula by that violently expanding bubble of energy.

Proximal Ejecta Distribution

- Around crater – swept into northern Ohio and Indiana,
  - where the deepest accumulation of glacial regolith is found
- To the Northwest – regolith swept into glacial till in IA, MN, KS
  - Balco [1] noted anomalous regolith loading in glacial tills deposited at ~800 ka
- To the West – Nebraska Rainwater Basins
- South & East – in areas of high relief,
  - The blanket is eroded off and fushed into Appalachian drainage basins
  - Anthony [2] Noted widespread, regional aggradation signal at ~ 800 ka
- 1000 km South & East – on flat costal terraces
  - The Carolina bays are formed in the blanket

1- Balco, Stone & Jennings, *Fate of the preglacial regolith beneath the Laurentide Ice Sheet,* unpublished

2- Darlene M. Anthony And Darryl E. Granger, 2006, *Five million years of Appalachian landscape evolution preserved in cave sediments*, Geological Society of America, Special Paper 404

However…

My Carolina Bay Survey, presented in a series of talks and posters, has been received well by the GSA community. My attempts at invoking a cosmic impact… not so much.

The suggestion advanced in this article may appear to many as too hypothetical to deserve the light of day. However…

Chemistry Nobel laureate Harold Urey wrote those words 60 years ago in closing a paper in Nature where he proposed that a comet delivered a glancing blow to the Earth to generate the Tektites found in Australia. He concluded with:

> *…the tektite problem has been, and is, one of the major puzzles to men "who pick up rocks and stop to think" …, and conservative proposals have been found to be inadequate.* Harold C. Urey, 1957, *Origin Of Tektites,* Nature V179

Tim Harris introduced me to the Tektite problem in the fall of 2014. He was intrigued that the crater responsible for a recent and extensive strewn field was missing – a problem with parallels to the Carolina Bays. Consensus proposals regarding the location of the Australasian tektite crater remain inadequate after 60 years of intense research, so perhaps it is time for informed speculation.

Tektites – Terrestrial Distal Ejecta

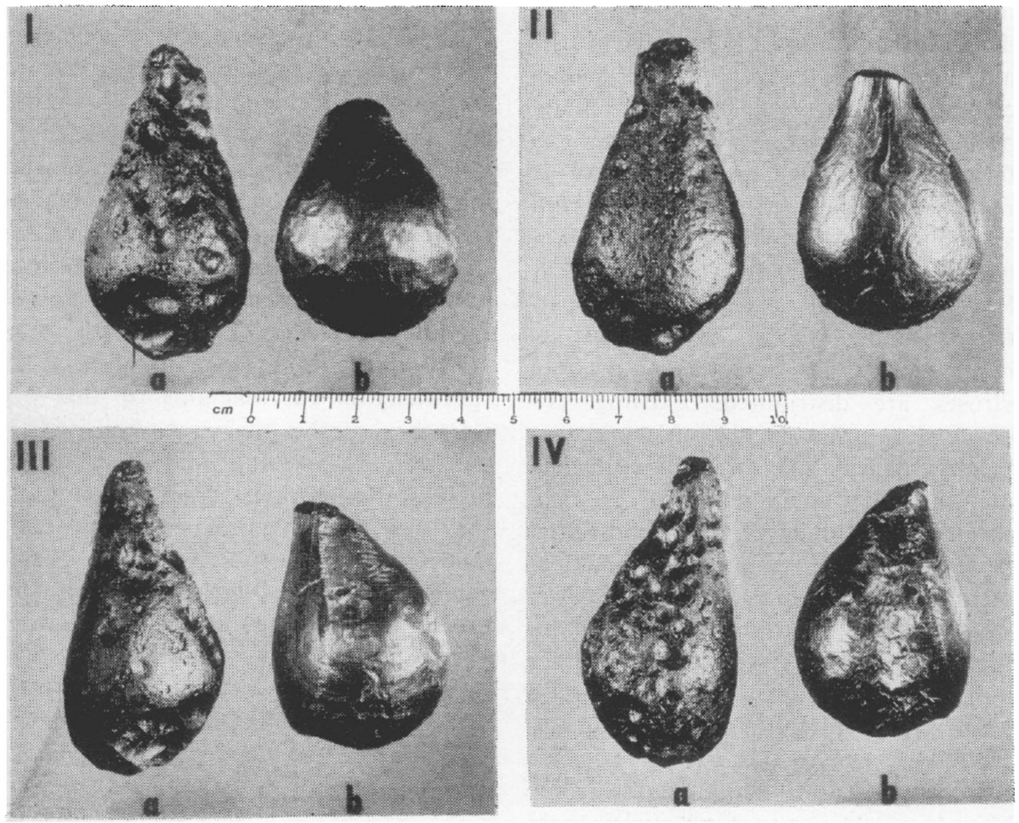


Fig. 1. Comparison of a spalled moldavite teardrop from Slavice (*a*) with a spalled australite teardrop from Renmark, South Australia (*b*). I, Anterior view; II, posterior view; III, side view, with posterior side to the left; IV, side view, with posterior to the right.

E. C. T. CHAO, 1964, Science Vol 146

Tektites are small, dark, glassy lumps that look a lot like obsidian.

Tektites from Central Europe (on the left in each image) are compared to those from Australia. We now know that these were created from terrestrial sediments ejected from different cosmic impact sites. Those from Europe are 15 ½ million years old, while the Australian examples have been confidently dated to 786 thousand years ago.

Ries Crater Tektites – Terrestrial Distal Ejecta

Numerical modeling of tektite origin in oblique impacts: Implication to Ries-Moldavites strewn field

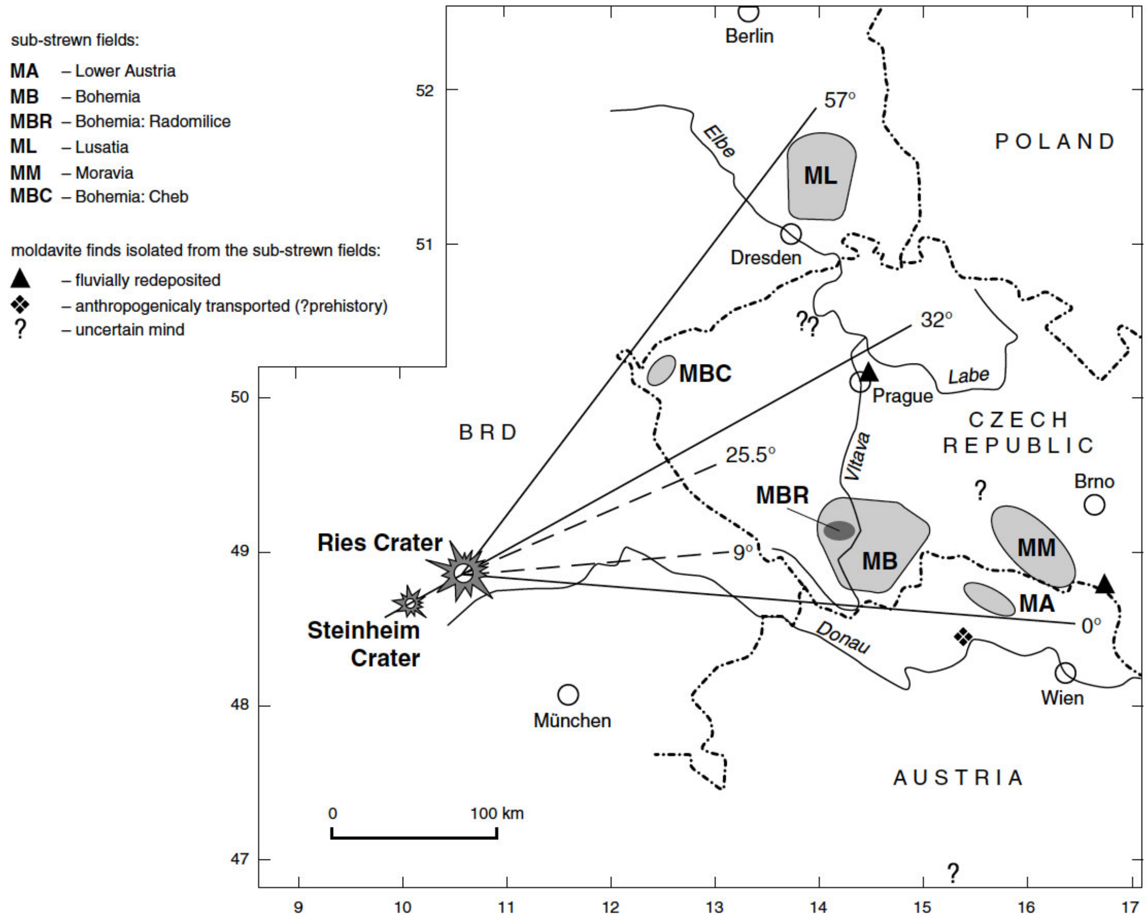


Figure 1. Map of Central Europe showing the Ries and Steinheim craters and the Moldavite strewn field (modified after LANGE, 1996); the sub-strewn-fields are hatched and explained in the legend; dashed lines (9° to 25.5°) define the fan within which coherent melt lumps are observed on the inner slope of the Ries crater rim.

The European tektites are associated with the Ries, Germany crater. Note the asymmetric distribution of tektites east from the crater site.

Fig 1, Artemieva, et al , 2002,

Ries Crater Tektites – Terrestrial Distal Ejecta

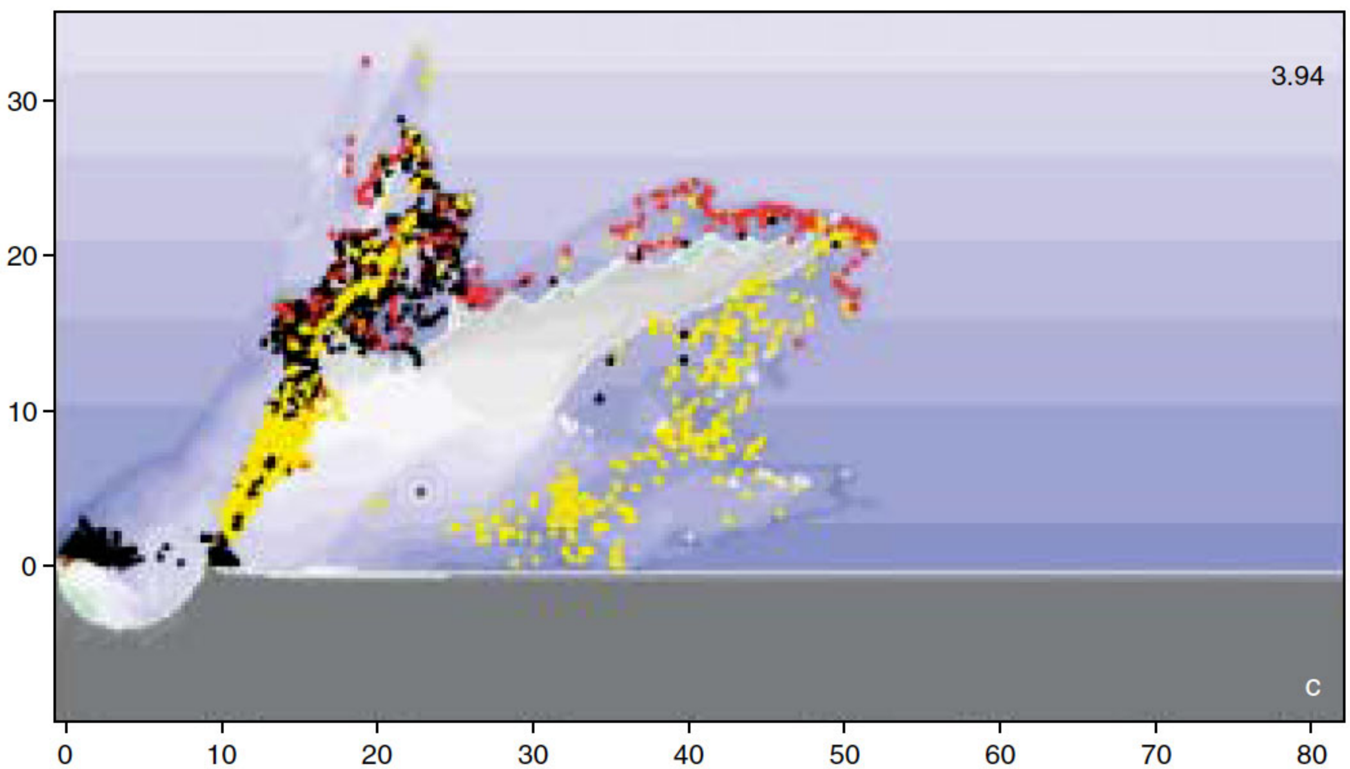
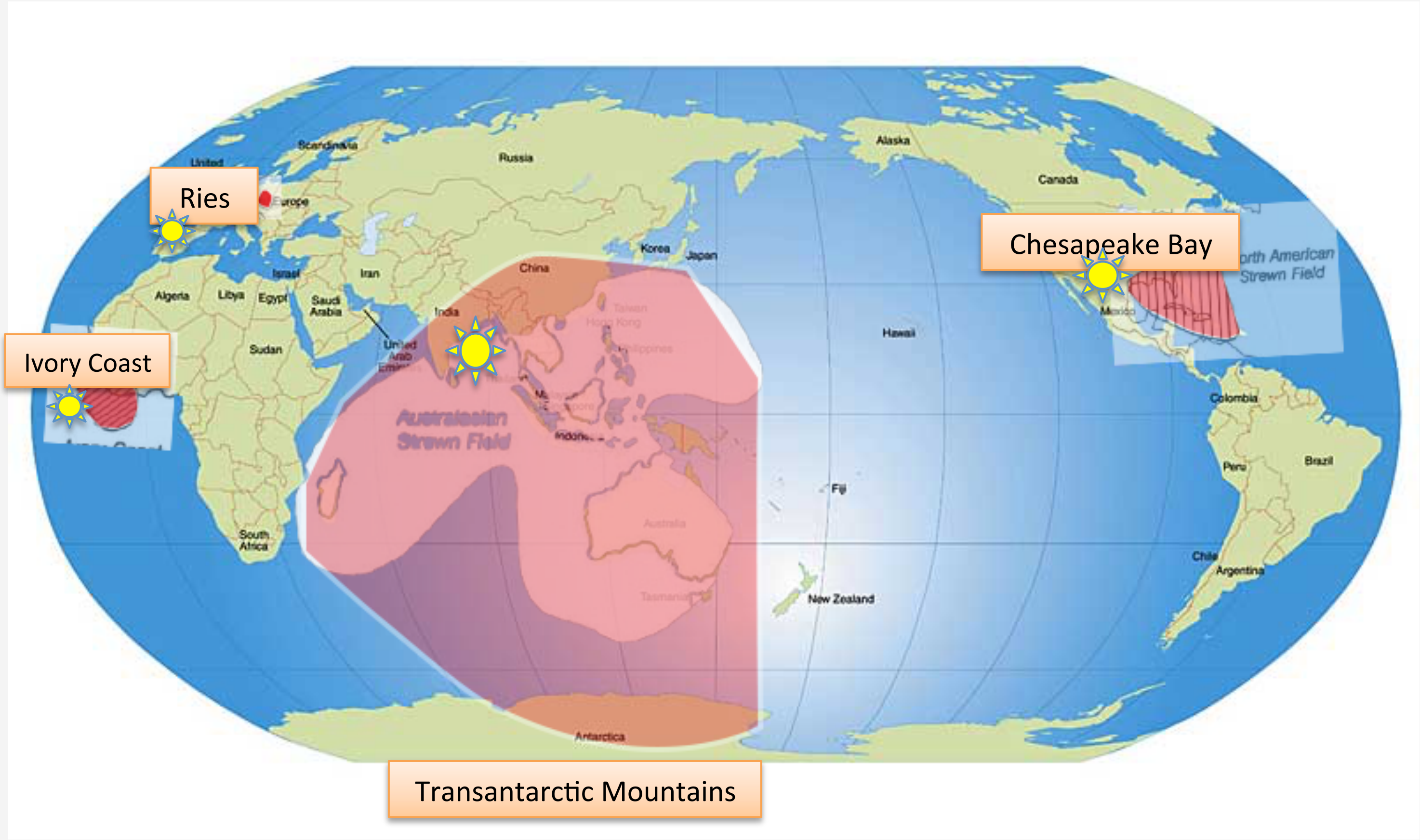


Figure 3. Tektite ejection model results for a 30° impact and impact speed of 20 km/s at a) 0.6 sec, b) 2 sec, and c) 3.9 sec. after the impact. ● – molten upper layer material (possible tektites); ● – molten target materials (not tektites); ● – solid target material.

Here is Artemieva's ejecta computational model for Ries, demonstrating how an oblique impact can generate a tektite strewn field down range along the impactor's arrival azimuth. Other experiments suggest that hydrated target materials enhance tektite production.

Fig 1, Artemieva, et al , 2002, Numerical modeling of tektite origin in oblique impacts, Bulletin of the Czech Geological Survey, Vol. 77, No. 4

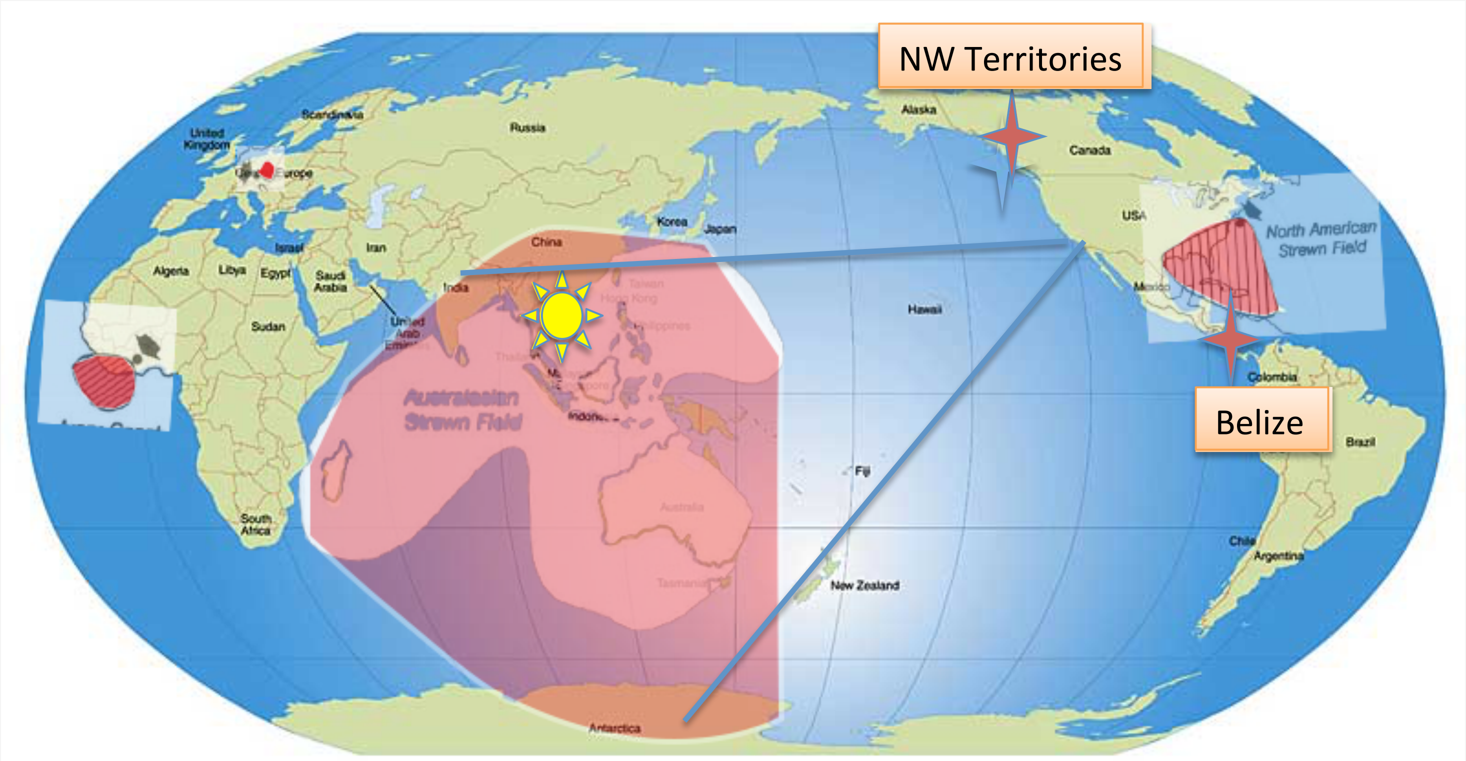
4 Known Tektite Strewn Fields



Out of over 170 identified astroblems on Earth, tektites have been associated with only four. They are very rare events. The Ivory Coast crater is 11km in diameter, Reis is 24, and Chesapeake Bay is 85.

Those three crater-strewn field pairings exhibit an asymmetric fan of tektites, and the nearest finds are 200 to 800 km removed from the crater.

Recent related tektite finds in North America



The Australasian field is ten times the size of the smaller fields combined. Hence, that tektite field and its missing astroblem form a **unique, singular event.**

Attempts to identify a crater in the midst of the strewn field in SE Asia have been unproductive. Perhaps not surprisingly, as it is not removed an adequate distance from the tektite finds.

Tektites are now being found in North America with dating indistinguishable from the Australasians, suggesting an inter-hemispheric event.

But is this any reason to implicate Michigan's Thumb?

In 1992, Joel Blum did a detailed Nd and Sr isotopic study of Australasian tektites. He identified two details of their evolution:The soil and rock excavated and lofted to become AA Tektites was near the surface and composed of sandstones, shales and greywacke laid down as fluvial deposits during the Jurassic ~ 175 Ma.

- A correlation of Rb/Sr fractionation with Sr model ages indicates that the last major Rb/Sr fractionation event experienced by the target materials occurred 175 ± 15 Ma ago. We interpret this age as the time of deposition of sedimentary target rocks and consider the compositional layering observed in Muong Nong-type tektites to reflect compositional variability inherited from Jurassic sediments.

Joel D. Blum, 1992, *Neodymium and strontium isotopic study of Australasian tektites: New constraints on the provenance and age of target materials,* Gmhrmica d Cosmuchimm ActaV ol.5 6,p p.4 83-492

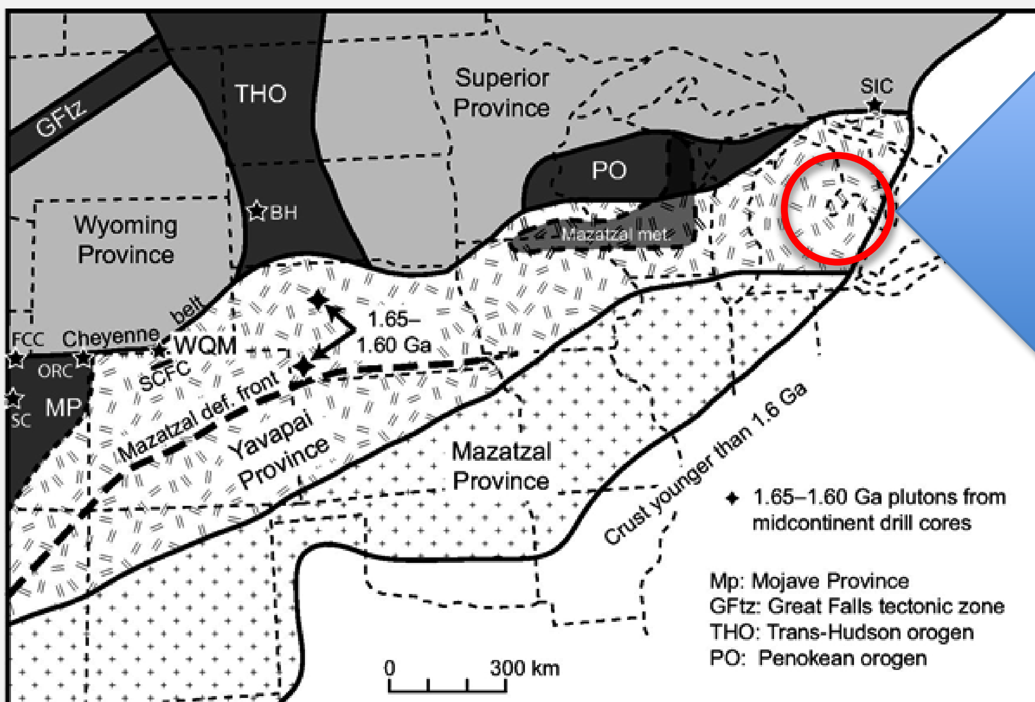
When Tim Harris informed me of Blum's work, and that the AA tektite source was sedimentary sandstones of Jurassic age, the same as the Michigan Red Beds, it suddenly clicked: what if the missing AA source crater and my missing Carolina bay crater were one and the same!

Forensic Evidence From AA Tektites

But it gets even more compelling: Blum also ascertained that the constituent grains were eroded from Proterozoic crust.

- Depleted mantle Nd model ages fall within the narrow range of **1490-1620 Ma,** indicating that the source material was derived dominantly from a **Proterozoic crustal terrene**

Joel D. Blum, 1992, *Neodymium and strontium isotopic study of Australasian tektites: New constraints on the provenance and age of target materials,* Gmhrmica d Cosmuchimm ActaV ol.5 6,p p.4 83-492



Charmingly, the Michigan Basin is surrounded by Proterozoic crust.

Jones, et al, 2012, *Reactivation of the Archean-Proterozoic suture along the southern margin of Laurentia during the Mazatzal orogeny: Petrogenesis and tectonic implications of ca. 1.63 Ga granite in southeastern Wyoming, GSA Bulletin V. 125 no. 1-2*

Michigan Basin Jurassic Sandstone Zircon Ages

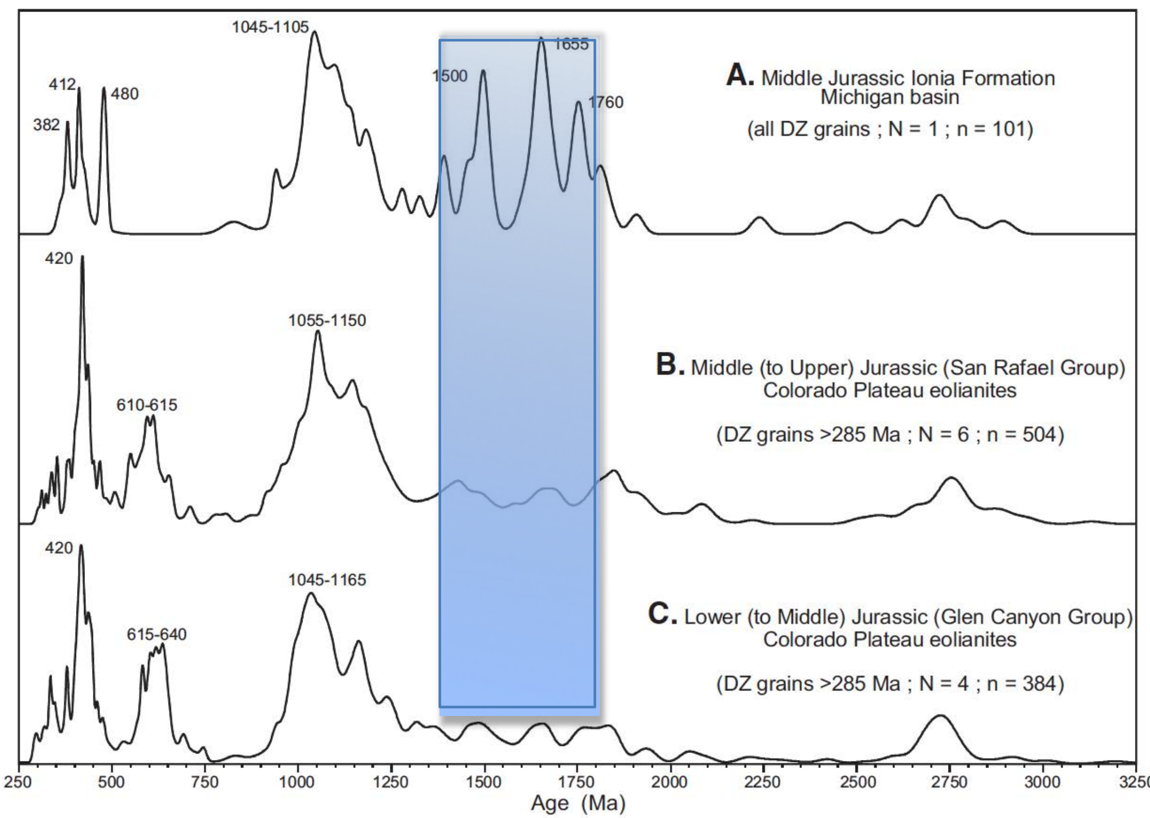
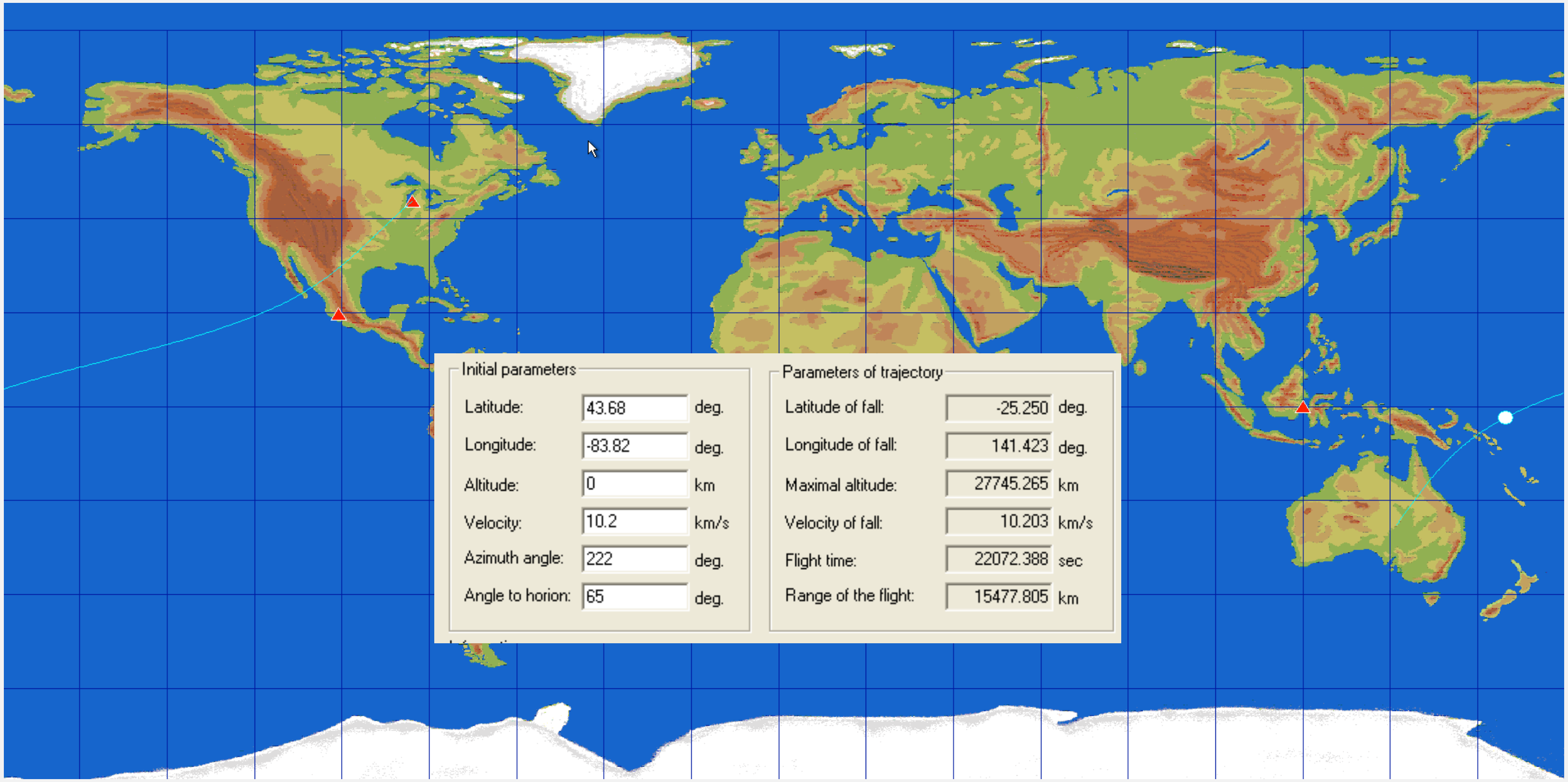


Figure 2. Age-distribution curves (normative age-probability plots) of U-Pb ages. A: Detrital zircon (DZ) grains in Ionia Formation of the Michigan basin. B, C: Detrital zircon grains older than 285 Ma in Colorado Plateau eolianites of Jurassic age. N—number of samples; n—number of grain ages.

Dickinson, et al, *Detrital zircons from fluvial Jurassic strata of the Michigan basin: Implications for the transcontinental Jurassic paleoriver hypothesis*, Geology 2010;38;499-502.

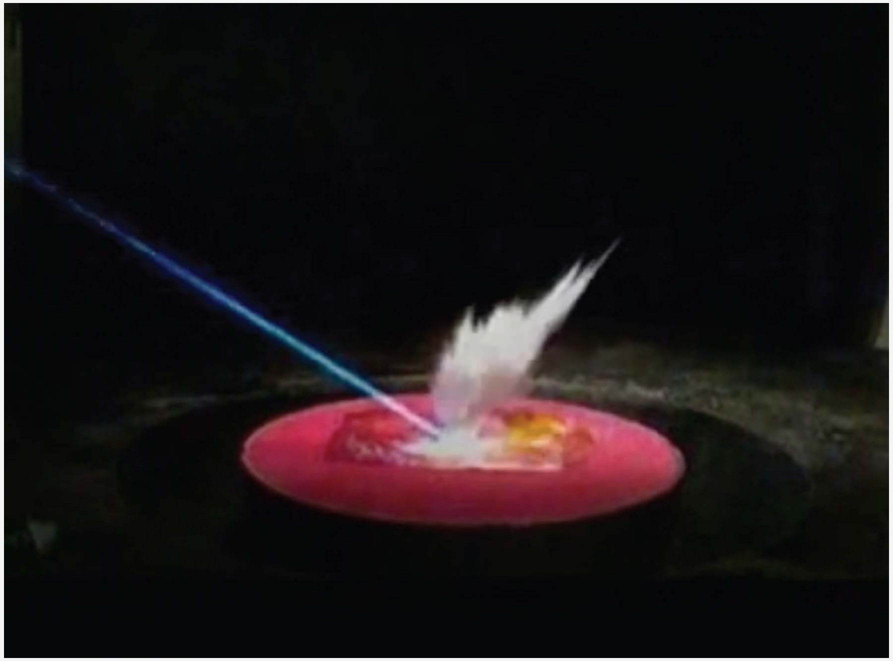
Here is Dickenson's graph with three examples of North American Sandstones of Jurassic age. Only the Michigan Basin "Red Beds" contain zircons with ages that correlate to the original source ages of the AA Tektites. Further, the Australasian event occurred during the depths of MIS 20, and the Michigan Basin would have hosted a deep ice sheet, as I have been modeling for my Saginaw Impact event.

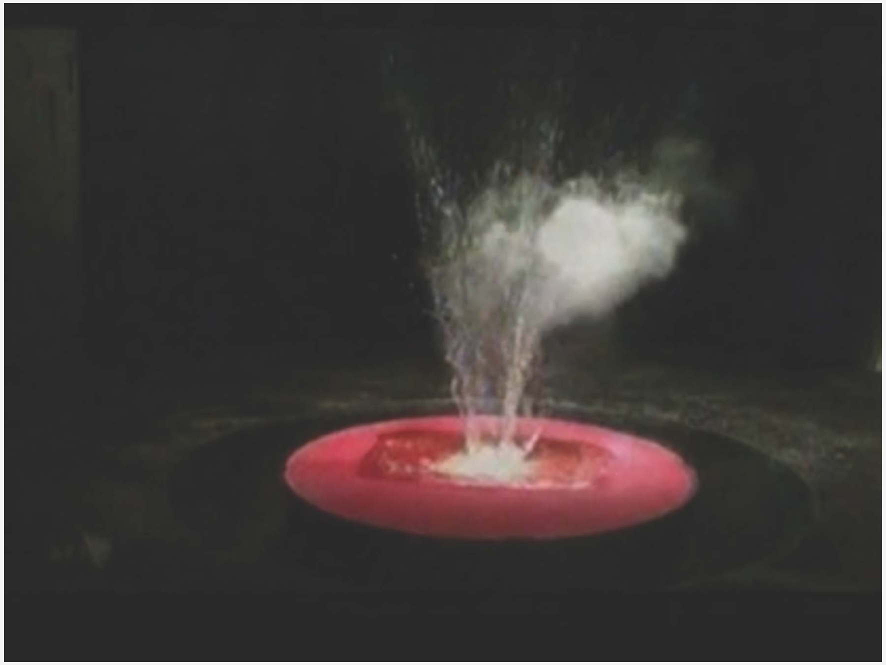
Orbit 1.2 Calculation



I did a quick set of sub--orbital calculations and, a bit disheartened, realized that getting to the Australia from Michigan would require lofting ejecta at high elevation angles, 28,000 kilometers out into space, at 10.2 k/sec - close to Earth's escape velocity. Not missing a beat ....

Oblique impact into ice





Tim shared with me these two images from Schultz's experiments with oblique impacts into ice, demonstrating that a plume erupts upwards from the impact site, with a bias down range. Such a plume has the ability to draw large fragments upwards at velocities higher than shock mechanisms seen in classic impact events.

Our hypothesis that the Australasians Tektite may have traveled interhemispheric distances is taken directly from this finding: for a tektite to re-enter the atmosphere at 10 kilometers per second, it must be launched away from the surface at that velocity and loft time is measured in hours – five to ten should be expected, during which the rotation of the Earth would bring the fall to an antipodal location. When Lin tackled the problem back in the 1990's, he suggested a Scandinavian location.

Button Flange AA Tektites

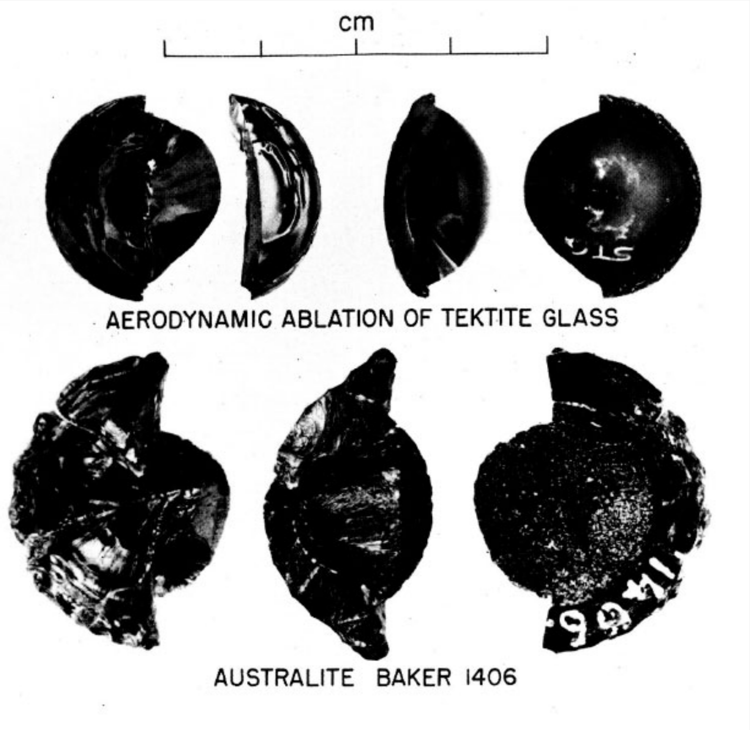
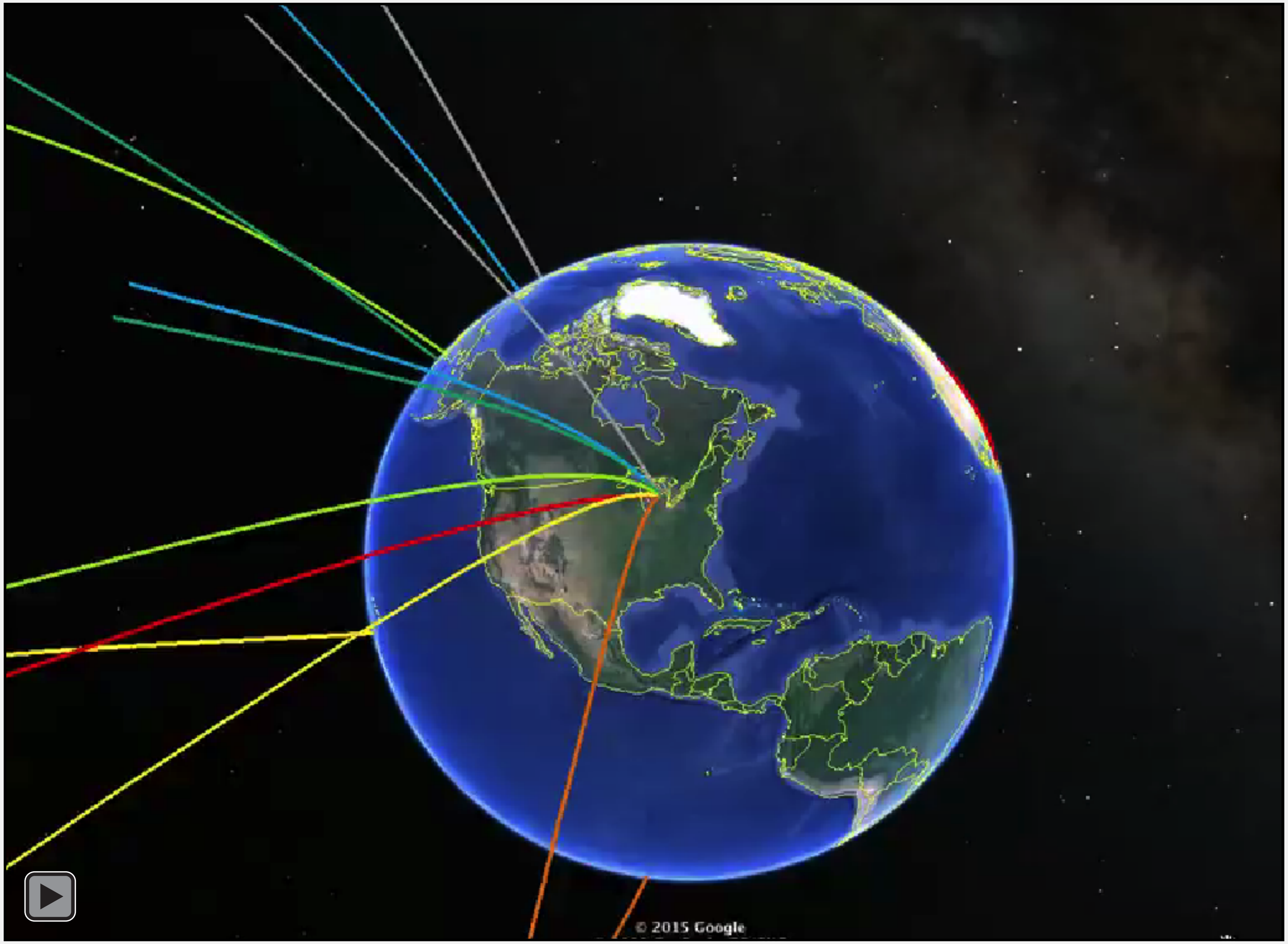


Fig. 4. Half spallation of aerothermal stress shell.

And yes, Virginia, it turns out that the Australian Tektites **did** travel far out into space at between 10 and 11 kilometers per second. Chapman demonstrated how these Button Flange tektites had fully solidified as a spheres in a vacuum and then remodeled during re-entry at >10 kilometers per second, close to Earth Escape.

Chapman, *On the unity and origin of the Australasian tektites, Geochimica et Cosmochimica Acta* 1964, Vol. 2

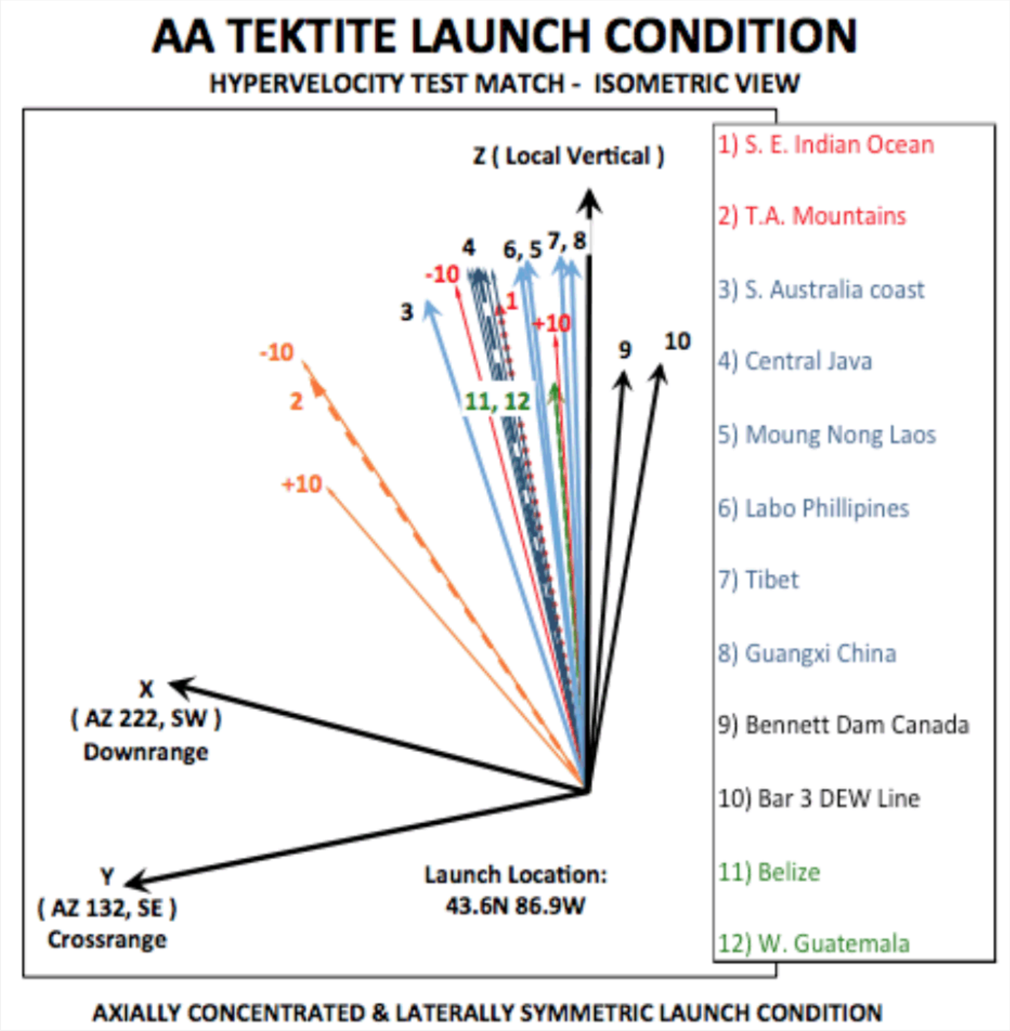
AA Tektite Tracks



Lets consider the adequately--potent impact into Saginaw: the loft time is measured in hours as the debris travels tens of thousands of kilometers out into space before gravity pulls it back, during which the Earth would rotate under the plume, providing the correct physics to deliver melted, then re--solidified, Michigan sandstone across the strewn field.

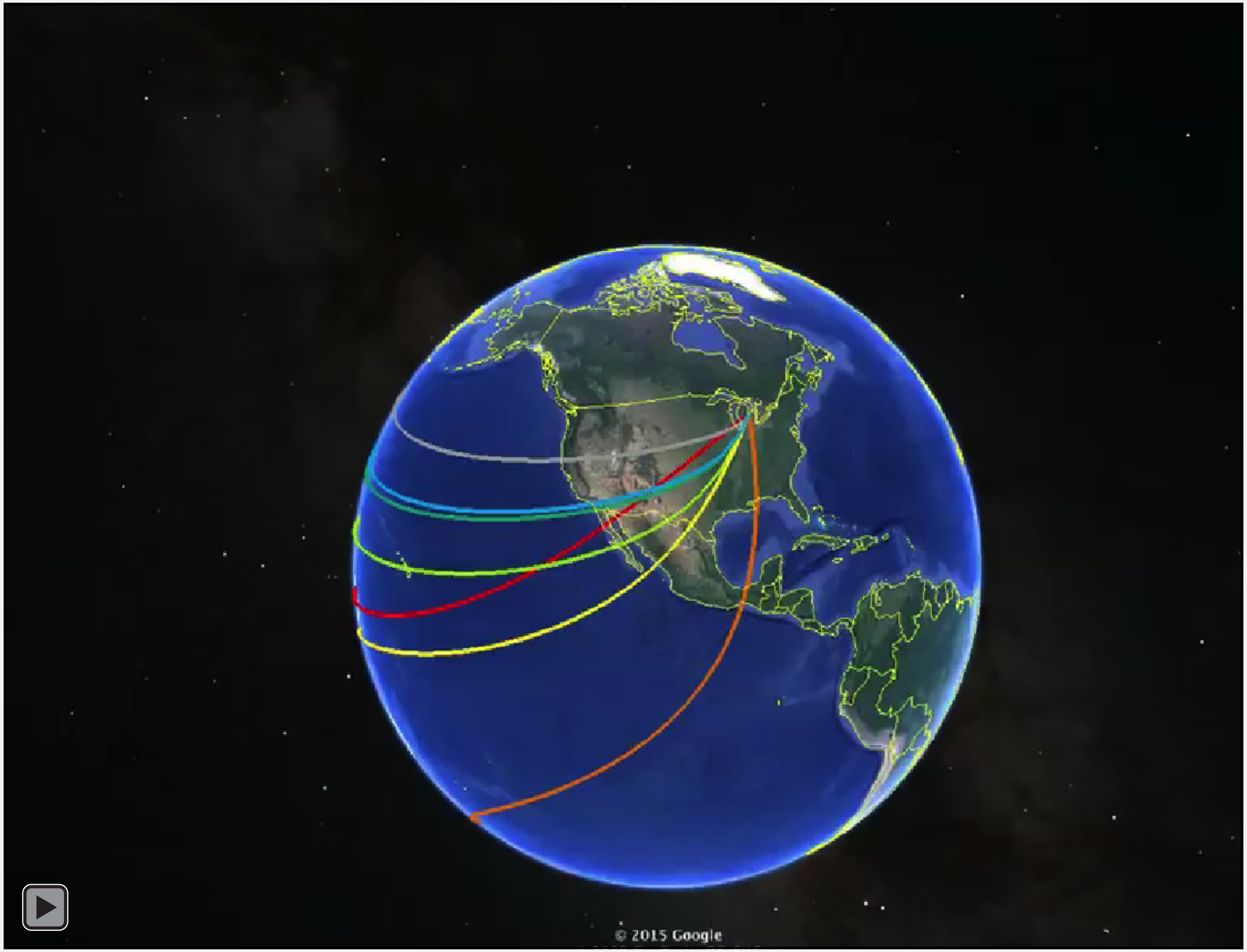
AA Tektite Launch Condition

Here is Tim's isometric view of those sample trajectories. The velocities are tightly constrained, **as is** the spread of launch elevation angles in the plume. The launch vectors are generally biased along 222º azimuth.



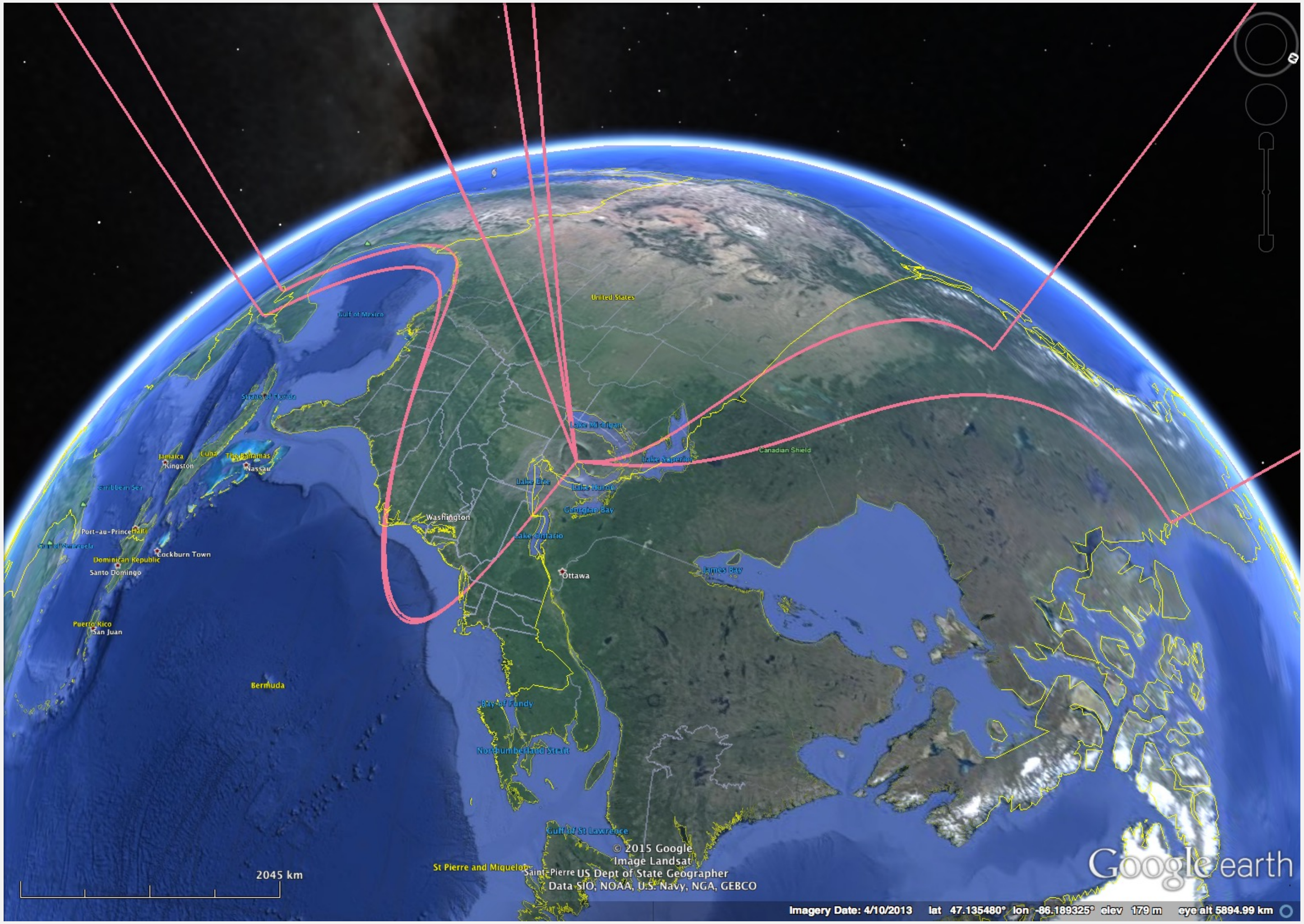
Harris & Povenmire, 2015, *Tektite Observations and Suborbital Analysis, LPSC* **#1291**

Tektite Ground Tracks



This animation shows the ground tracks of the same set of trajectories.

Belize and NW Territories Tektite Trajectories



The Belize and the Northwest Territories trajectories mirror each other, and represent lofts just a bit back up range

Saginaw Manifold Summary

- ✓ Two massive & recent impact astroblems are unaccounted for
- ✓ Oblique Impacts into ice may be easily "Lost"
- ✓ Tektite production seems related to oblique impacts and hydrated sediments
- ✓ Carolina bay orientations triangulate to Saginaw Bay
- ✓ The Saginaw posited crater represents an impact into hydrated sediments
- ✓ Michigan Red Beds chemistry correlates to Australasian Tektites
- ✓ Material in a Plume from Saginaw bay @ 10k sec^{-1} reaches AA tektite finds
- ✓ Anomalously high glacial till and drainage basin aggradation rates in NA ~800ka

Carolina bays, Australasian tektites, and Saginaw Bay

generated from single cosmic impact ~786 ka

Into Lower Peninsula of Michigan

Avenues For Future Work

There is much more to accomplish. Just as LiDAR has facilitated the bay Survey, we suspect that new technology using Beryllium / Aluminum isotope ratios will assist our dating challenges.

- Apply ^{10}BE / ^{26}AL burial dating technology
- Differentiate between bay structural rims and surficial dunes
- Test regolith in till and moraines for 800ka & impact signatures
- Test Carolina bay structural rims for 800ka & impact signatures
- Compare Carolina Bay deposits to Michigan Basin sandstones
- Relationship with Matuyamas/Brunhes geomagnetic reversal
- What drives the variations in bay shape?
- Did this event drive the "Mid-Pleistocene Revolution"?

If the hypothesis has any merit, it may provide an explanation for the "Mid-Pleistocene Revolution" 800,000 years ago, during which extensive geological transitions have been noted.

A Tale Of Two Craters: Coriolis-aware Trajectory Analysis Correlates Two Pleistocene Impact Strewn Fields And Gives Michigan A Thumb

Pleistocene Epoch cosmic impacts have been implicated in the geomorphology of two enigmatic events. Remarkably, in both cases spirited debates remain unsettled after nearly 100 years of extensive research. Consensus opinion holds that the Australasian (AA) tektites are of terrestrial origin despite the failure to locate the putative crater, while a cosmic link to the Carolina bays is considered soundly falsified by the very same lack of a crater. Likely >100 km in diameter, these impacts during geologically recent times should be readily detectable on the Earth's surface. The improbability that two craters have eluded detection informs a hypothesis that a single impact at ~786 ka generated AA tektites as distal ejecta and Carolina bays as progeny of proximal ejecta. The AA astroblem search is focused on SE Asia despite a strewn field encompassing >30% of the Earth's surface. This spatial scope implies to us that interhemispheric transits should be considered, as does findings that AA tektites were solidified in a vacuum, then ablated on re-entry at ~10 km sec-1. A Coriolis-aware triangulation network operating on the orientations of 44,000 Carolina bays indicates a focus near 43ºN, 84ºW. Referencing the work of Urey and Lin, we propose that a near-tangential strike to the Earth's limb generated the 150 x 300 km oval depression that excises Saginaw Bay and opens Michigan's Thumb. That region was likely buried under deep MIS 20 Laurentide ice at 786 ka. Schultz has shown that oblique impacts into continental ice sheets yield non-traditional astroblems, and multiple glaciations have since reworked this site, making identification more challenging. Hypervelocity gun tests show that oblique impacts produce a vertical plume of ejecta, biased slightly down-range. Ballistic trajectories reflecting such a plume deliver tektites to all AA finds when lofted at ~10 km sec-1 and parameterized with the proposed depression's location and 222º azimuth. Chemical and isotopic characteristics of AA tektites suggest they were sourced from sandstone and greywacke of Mesozoic age, which is congruent with Michigan Basin strata lost when The Thumb developed. The distribution of proximal ejecta may explain anomalous pulses of regolith in moraines and sediment loading in regional drainage basins recently dated ~800 ka using 10Be/26Al methods.

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