Getting More From Gravity & Magnetics: Examples From Mexico*

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Abstract

Potential fields provide a cost-effective way to explore large areas for oil and gas. Euler deconvolution is an established algorithm to extract features from potential fields. We use an enhancement to the conventional Euler deconvolution process to identify lineaments typically associated with faults, fractures, etc. Designated EASI for Euler Angle Stack Imaging, this tool has been effectively used in many areas around the world, both with high resolution surveys and with large regional data grids. EASI provides a much cleaner set of lineaments with less noise and better resolved orthogonal faults than conventional Euler deconvolution. While these lineaments provide useful insight by themselves, they are best utilized with independent sources of data such as seismic, seepage, or production data. In this talk we will look at some established structures, existing oilfields, the Chicxulub impact crater, and potential new exploration areas in Mexico to see what this process can reveal using public domain gravity and magnetic grids. The lineaments show good correlations with known fields and reveal interesting discoveries regarding Chicxulub.

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Padilla y Sánchez, R.J., I. Domínguez Trejo, A.G. López Azcárraga, J. Mota Nieto, A.O. Fuentes Menes, F. Rosique Naranjo, E.A. Germán Castelán, and S.E. Campos Arriola, 2013, National Autonomous University of Mexico Tectonic Map of Mexico GIS Project, American Association of Petroleum Geologists GIS Open Files Series. http://www.datapages.com/AssociatedWebsites/GISOpenFiles.aspx Website accessed June 2018.

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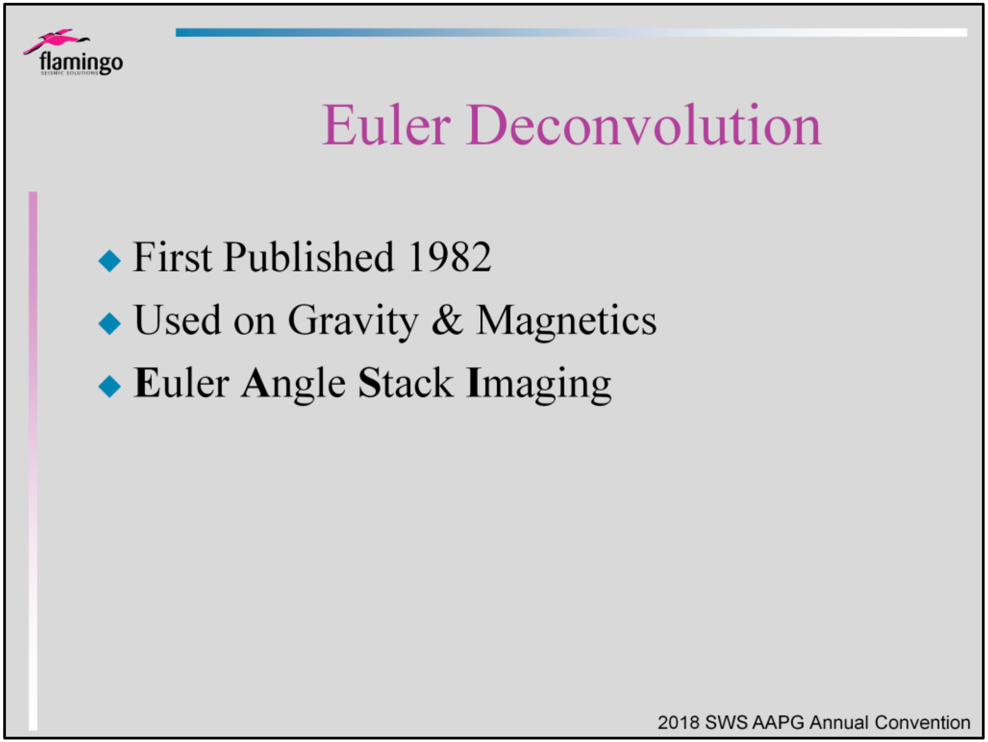
Getting More From Gravity & Magnetics: Examples From Mexico

Ray Earley (presenter)
Ted Lautzenhiser
Glenn Felderhoff

Outline

- EASI technology to compute lineaments
- Golden Lane
- Cantarell / Zama-1 area
- Chicxulub impact site
- Summary

We begin with a brief description of the EASI process, then examine its results in the areas of the Golden Lane fields, Cantarell fields, Zama-1 well, and the Chicxulub impact site to see how it relates to those known features.



The EASI process is based on the Euler Deconvolution method first described by Thompson (Geophysics, 1982). It uses as input a gridded field of gravity or magnetic data. The enhancements we have made will be described briefly here.

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Examples of Deconvolution Applications

- Radar
- Vibroseis
- Seismic Wavelet Deconvolution
- Facial Recognition

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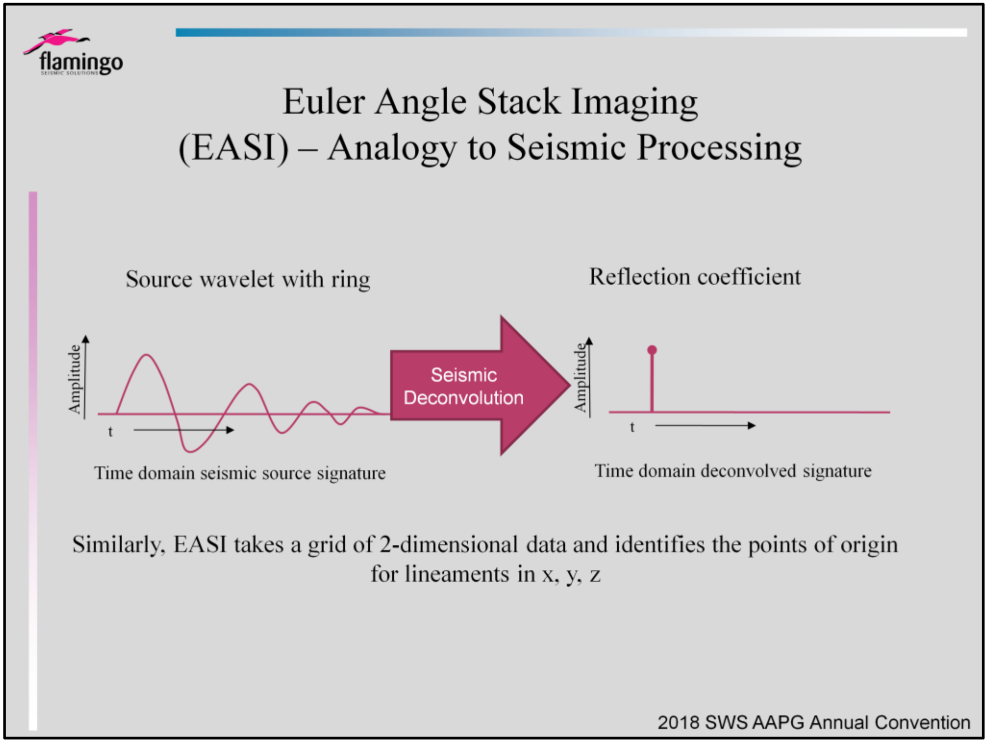
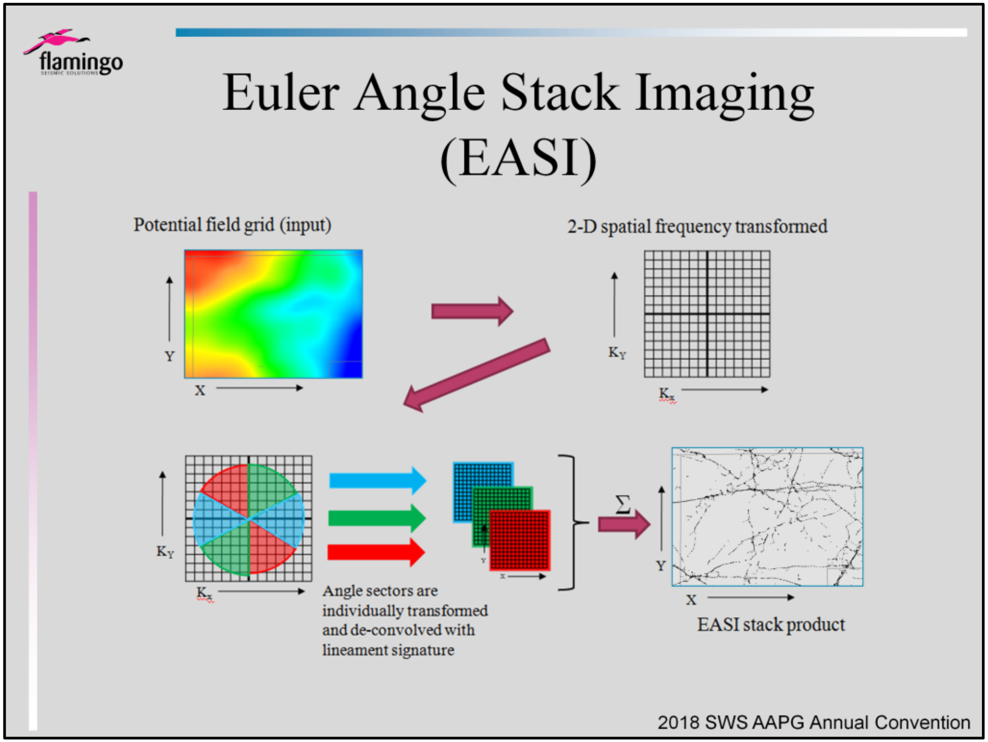
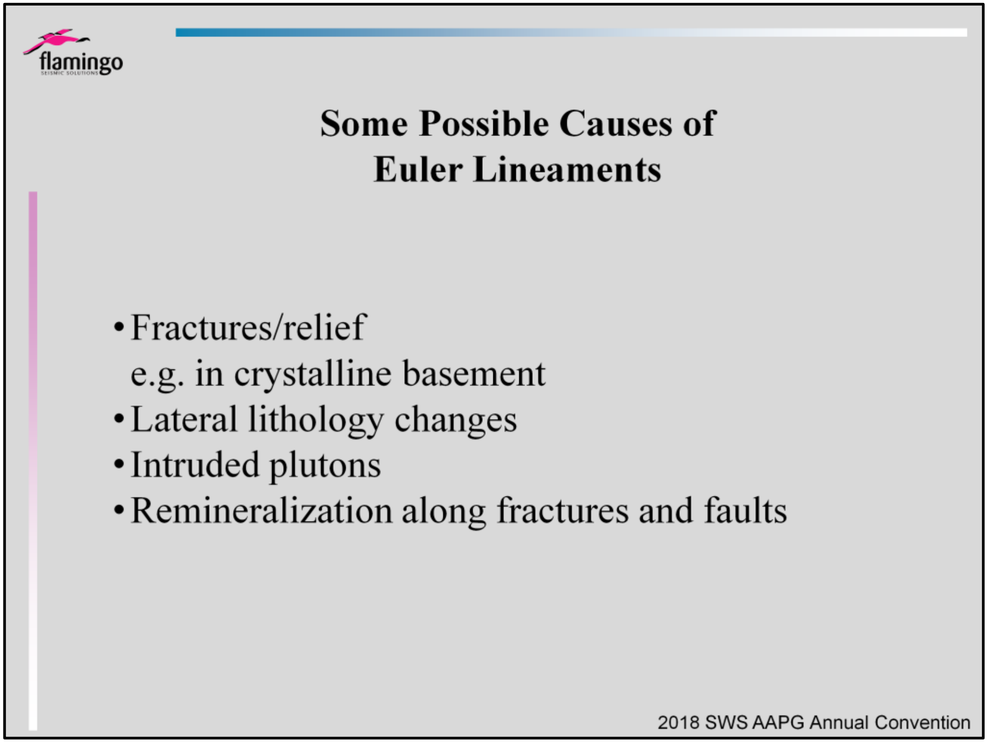
Mindful of Clarke's third law: "Any sufficiently advanced technology is indistinguishable from magic", without going into any mathematical detail, we will look at the process to see that it is based on sound principles. It has similarities to a number of various technologies which extract low level signal from high levels of noise. A more familiar analogy for two dimensional grids of data might be facial recognition.



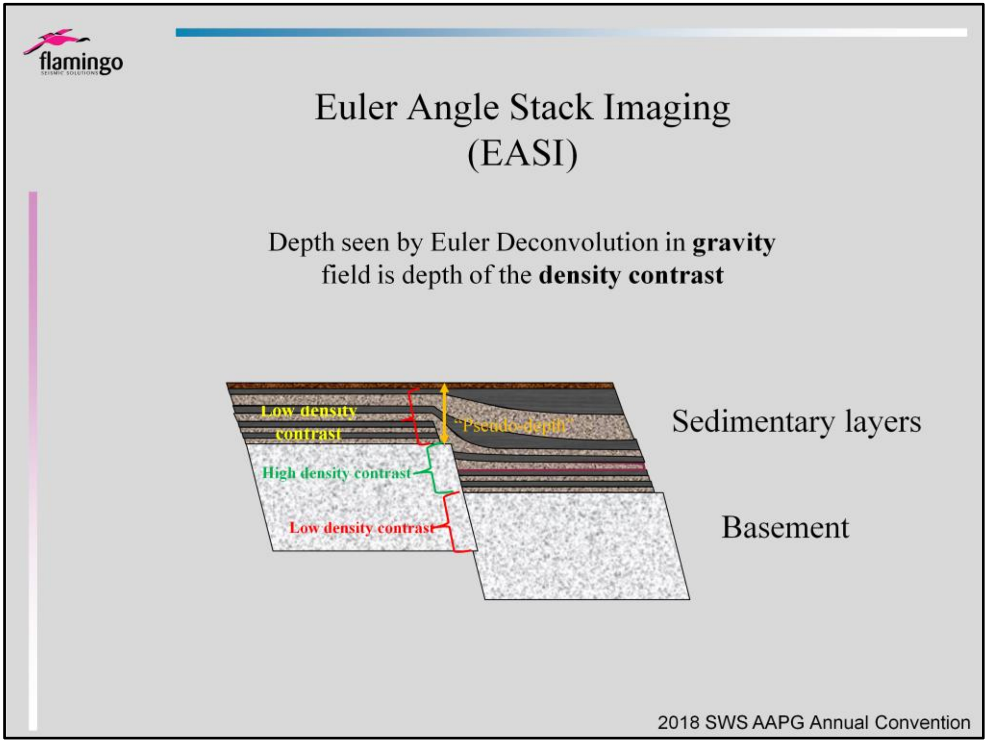
One analogy from the seismic world would be conventional deconvolution. Seismic deconvolution takes a seismic source wavelet and estimates where in time the causal reflection coefficient would be, collapsing the wavelet down to a single point. In a similar fashion, Euler deconvolution steps through a field of gravity or magnetic data identifying where the field satisfies Euler's equation for a lineament, yielding a point in x, y, z space.



The EASI enhancement to Euler Deconvolution first transforms from the spatial X, Y domain to the spatial frequency domain. There it is azimuthally sectored (shown here with three sectors, although in practice it is more than three) to separate out features at different angles, and transformed back to the spatial X, Y domain. The Euler deconvolution is then run on each of these sectors, and the results are summed with a noise reduction process to produce the EASI lineaments. This azimuthal sectoring helps to resolve intersecting lineaments. Although a few of the lineaments produced are ones that are visually evident on the input data, many are not at all obvious.



Some of the types of things that can give rise to these lineaments include fractures or relief (such as might be in the crystalline basement), lateral changes in lithology, intruded plutons, and remineralization due to fluid flow along fractures and faults; basically anything linear that generates a contrast in density or magnetic susceptibility which can influence the measured field.



This cartoon provides a visual depiction of one type of geology which might give rise to EASI lineaments: a dip-slip fault. The EASI result from gravity will be the depth to the contrast in density or magnetic susceptibility, whether in the basement, basement against sediment (depicted here), or within the sedimentary layer.

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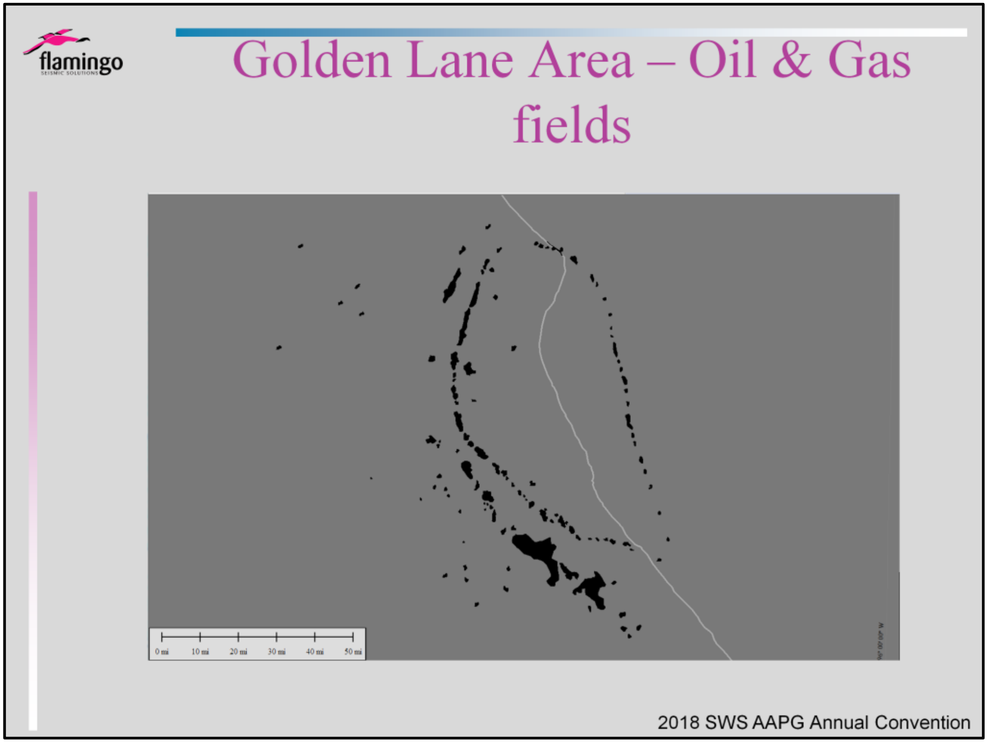
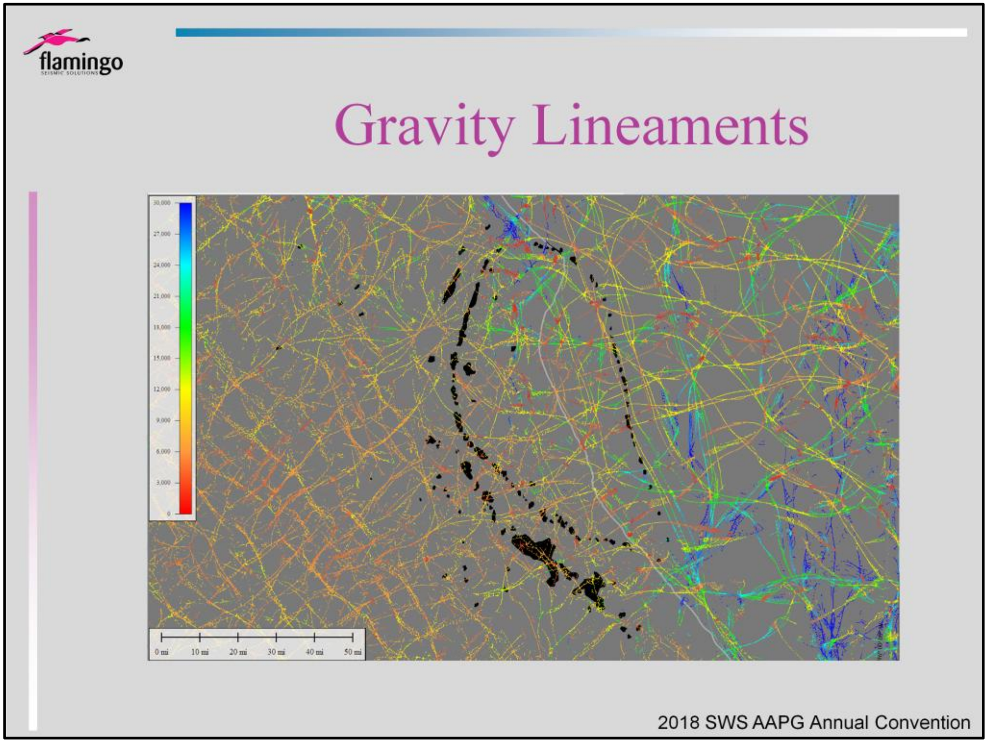
The first area to be examined is the Golden Lane trend on the east coast of Mexico.

This area has one of the most productive groups of fields in the world. Discovered in 1908, it includes one of the most productive wells in the world, the Cerro Azul #4.



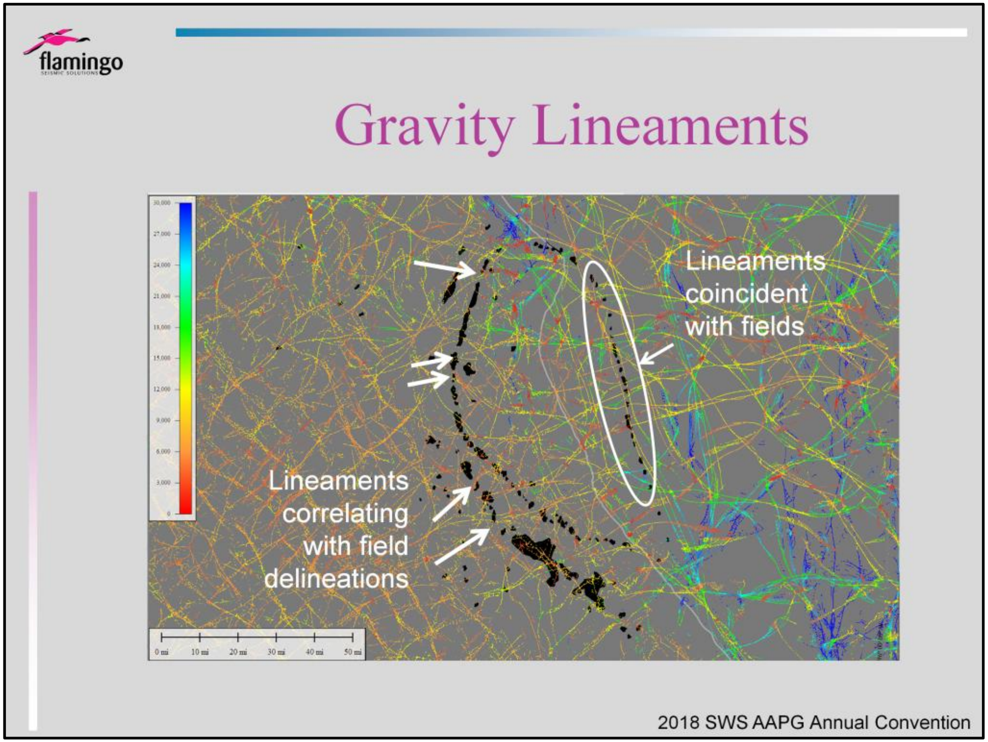
The Golden Lane fields are along either side of an ancient reef structure, both onshore and offshsore.



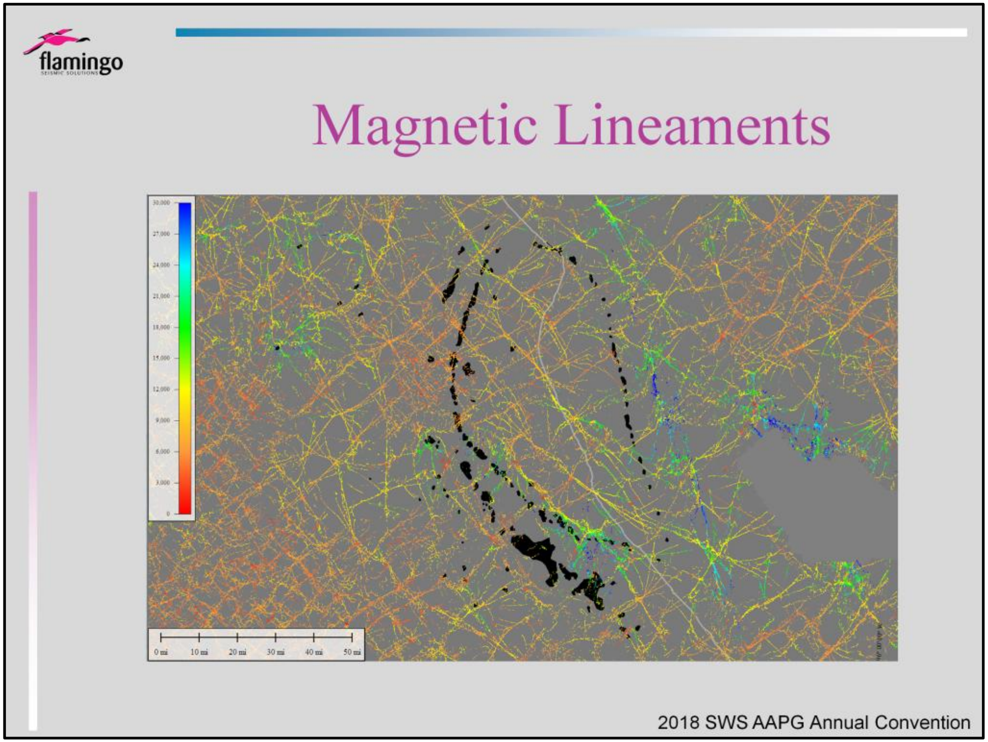
In all of the figures with color coding by depth, we use the same color bar with blue for deep and red for shallow.

With the EASI lineaments superimposed on the oil & gas fields, we can see a set of lineaments aligned with the offshore set of fields.

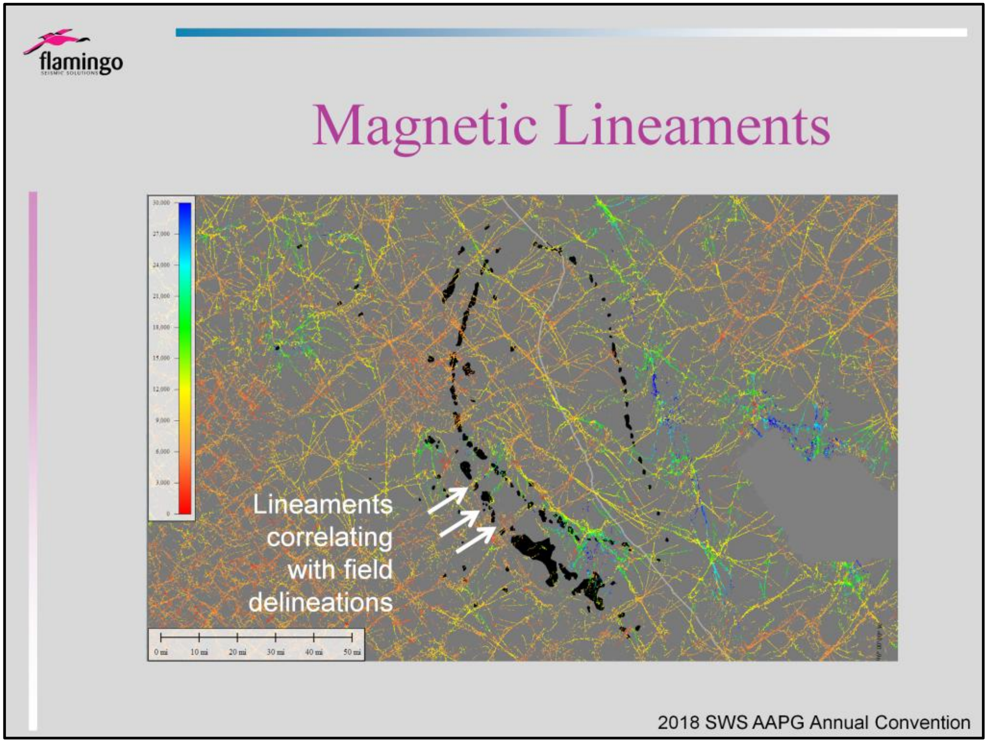
We also note that the onshore lineaments are generally shallower than the offshore ones, and there is a general character difference between the onshore and offshore lineaments.



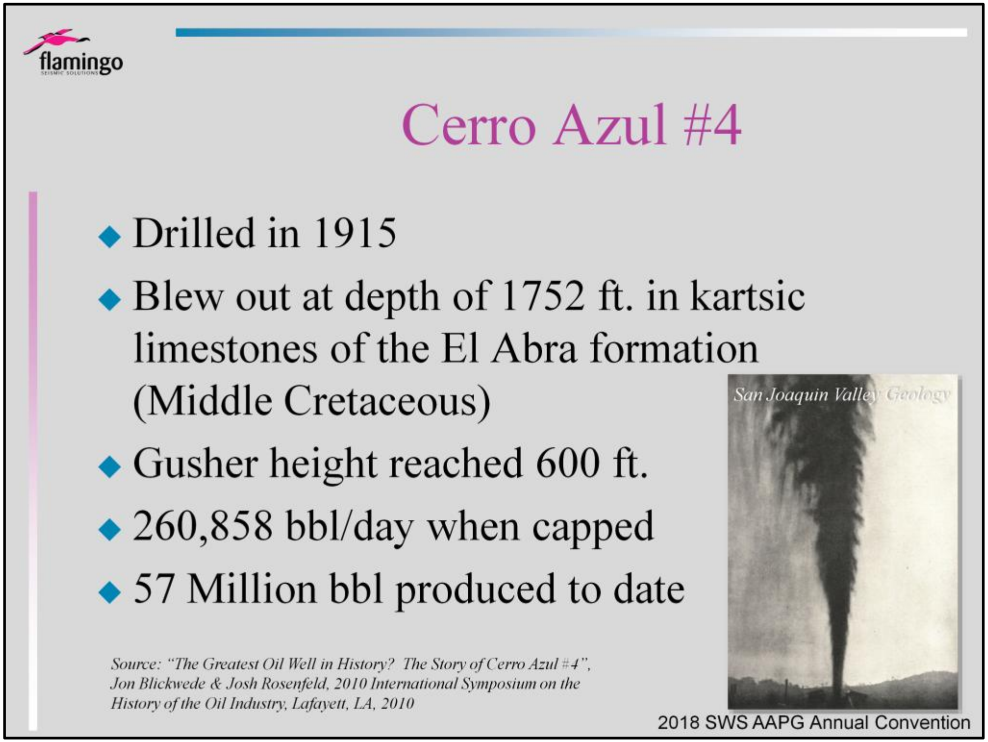
We see that onshore gravity lineaments are associated with the delineations of some of those fields.



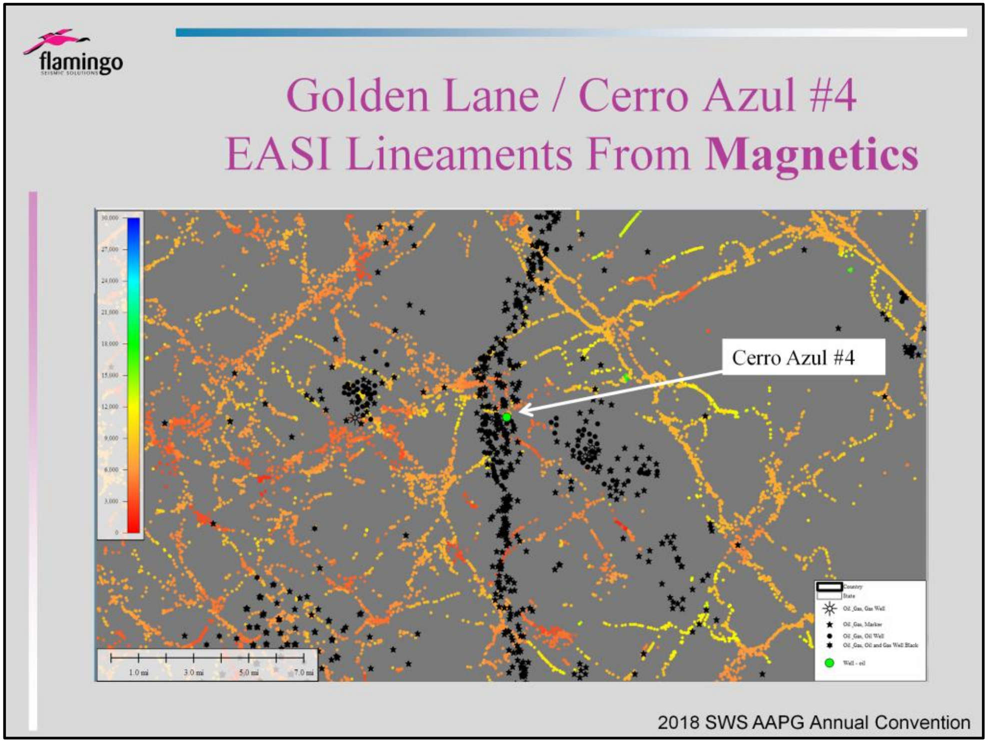
Here we have the magnetic lineaments as an overlay on oil & gas fields.



An examination of the magnetic lineaments also shows correlation between the lineaments and the delineations of many of the fields. We can also see a character change within the bounds of the fields (in the reef structure), as well as a band of deeper lineaments to the east (further offshore) of the reef structure. (There is a "no data" zone in the southeast portion of the map).



In the Golden Lane trend is a well that has been characterized as perhaps "The Greatest Oil Well in History". The Cerro Azul #4 blew out to 600 ft, produced 260,858 barrels per day when it was finally capped, and has produced 57 million barrels to date.



Looking in detail at the area of the Cerro Azul #4, showing individual wells, we see a confluence of magnetic lineaments, which is often found in EASI lineaments in areas of production. We also note terminations of several lineaments along the edge of the reef as determined by the well locations.

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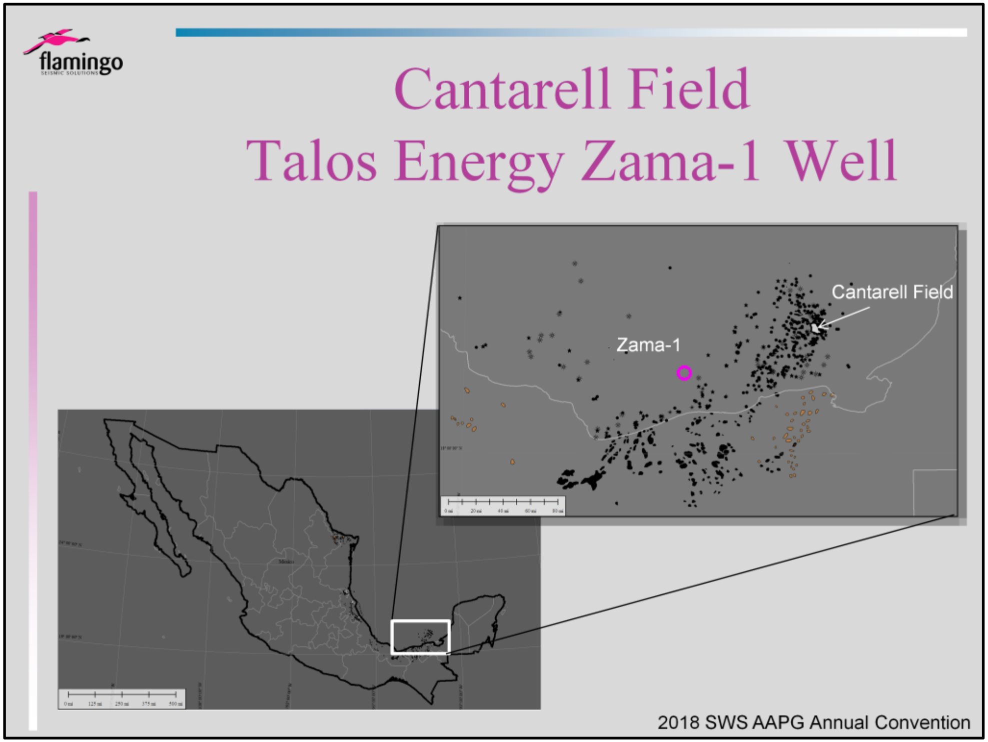

Next we examine two area in Bay of Campeche, the Cantarell field and the recent Zama-1 discovery.

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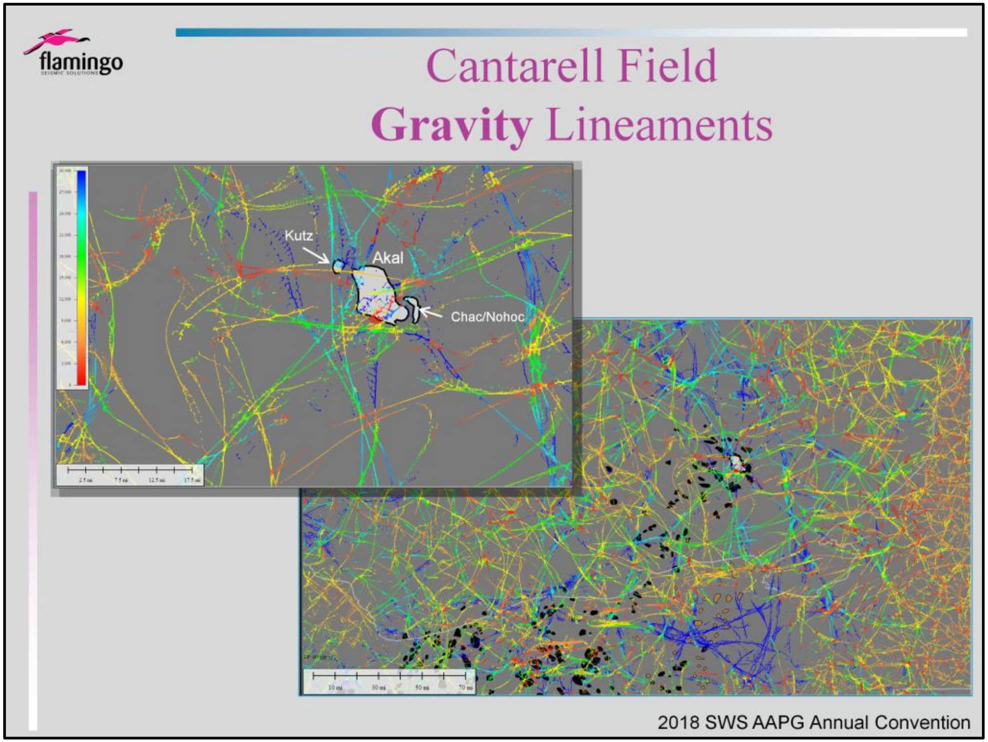
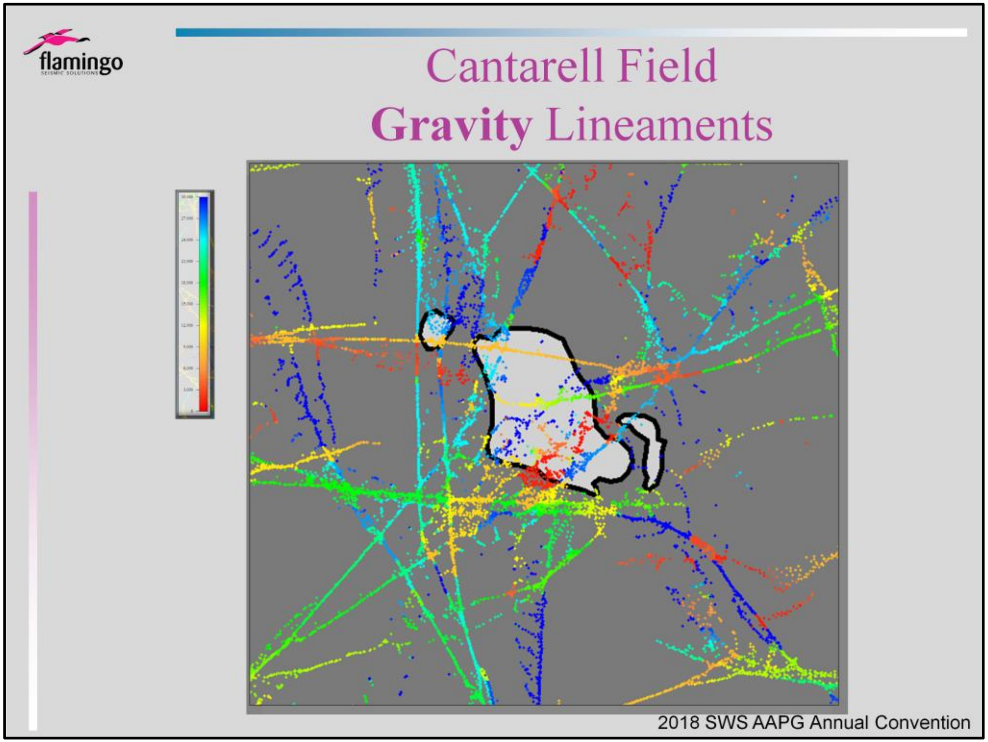
Cantarell Field

- Discovered 1976
- 3,000 ft pay zone
- Production peaked in 2004 at 2.14 million barrels/day
- Produced 11.5 billion barrels as of 2006
- Comprises 4 blocks: Akal, Nohoc, Chac & Kutz

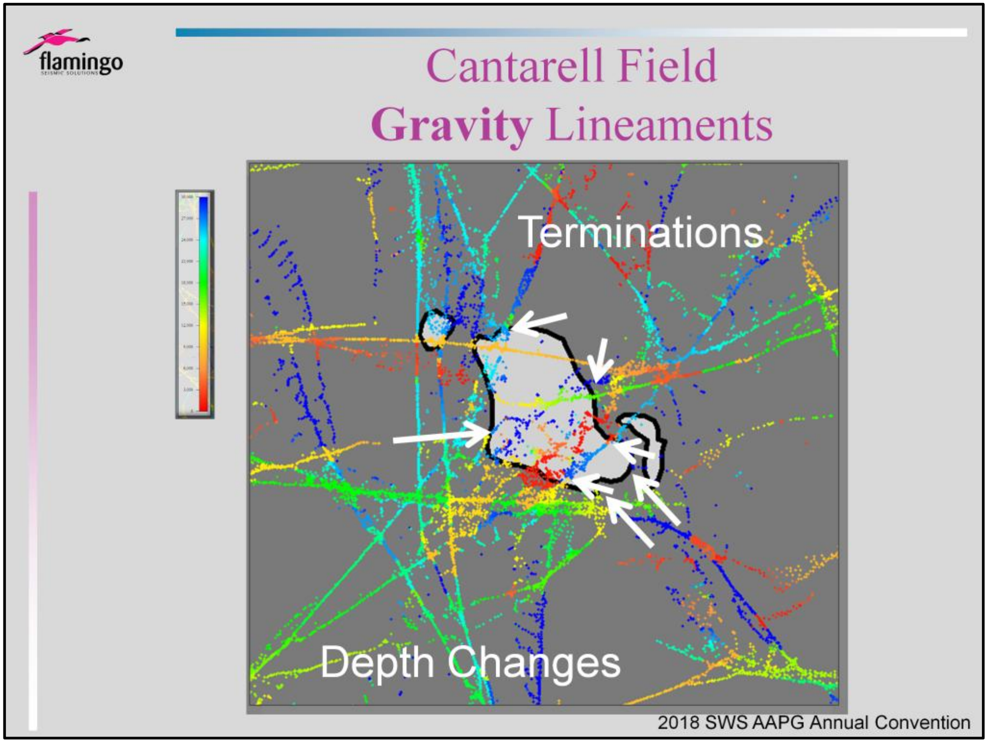
The Cantarell field has been a major producer since its discovery in the mid 1970’s, peaking at 2.14 million barrels/day in 2004. The major blocks are Akal, Nohoc, Chac and Kutz



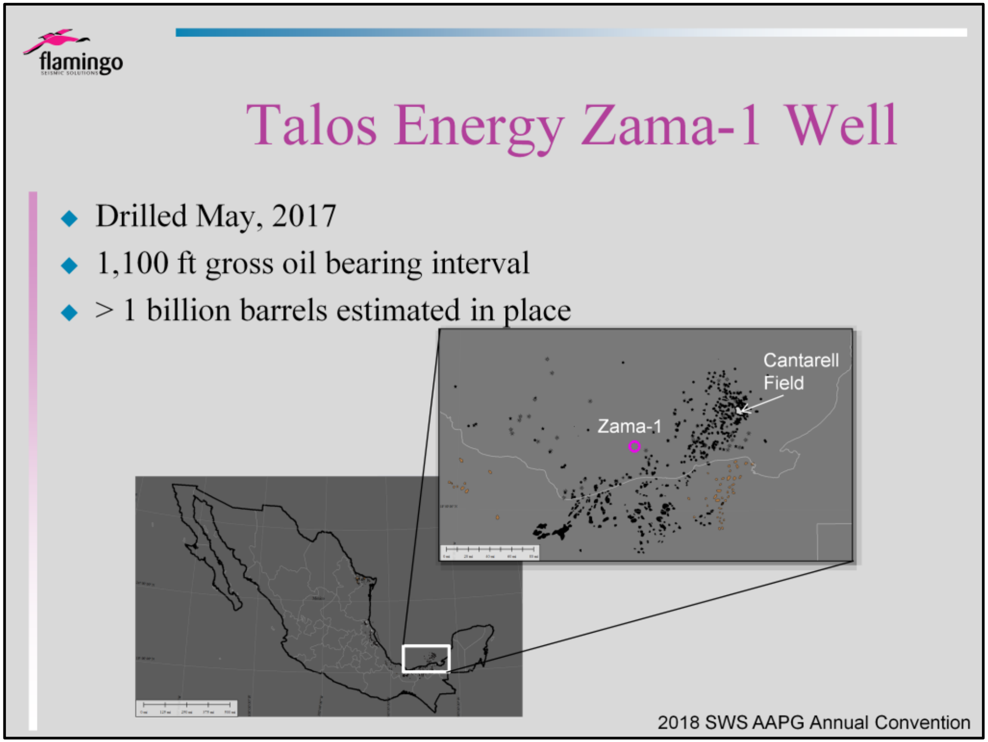
At a large scale, we see a deep set of lineaments from southwest to northeast, and another set of deep lineaments from northwest to southeast converging in the area of the main fields.



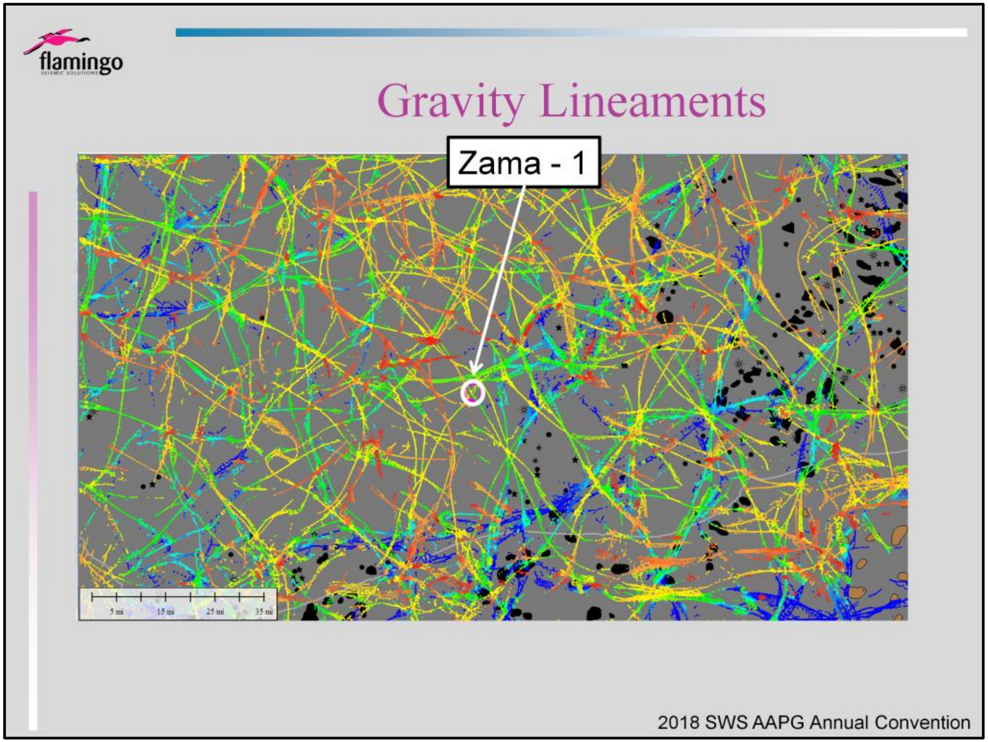
This is a zoomed in look at those four main blocks with the gravity lineaments.
We only look at gravity lineaments here because this is a no data zone for the public-domain magnetic data we have been able to find.



We can see terminations or depth changes in the gravity lineaments at the field boundaries. These terminations and depth changes are often significant.



Southwest of the Cantarell field is the Zama-1 discovery well, drilled last year. With 1,100 ft of gross oil bearing interval, and over 1 billion barrels estimated in place, it is a major find.



The gravity lineaments at the Zama-1 well again show a confluence of lineaments, several of which have long extents.

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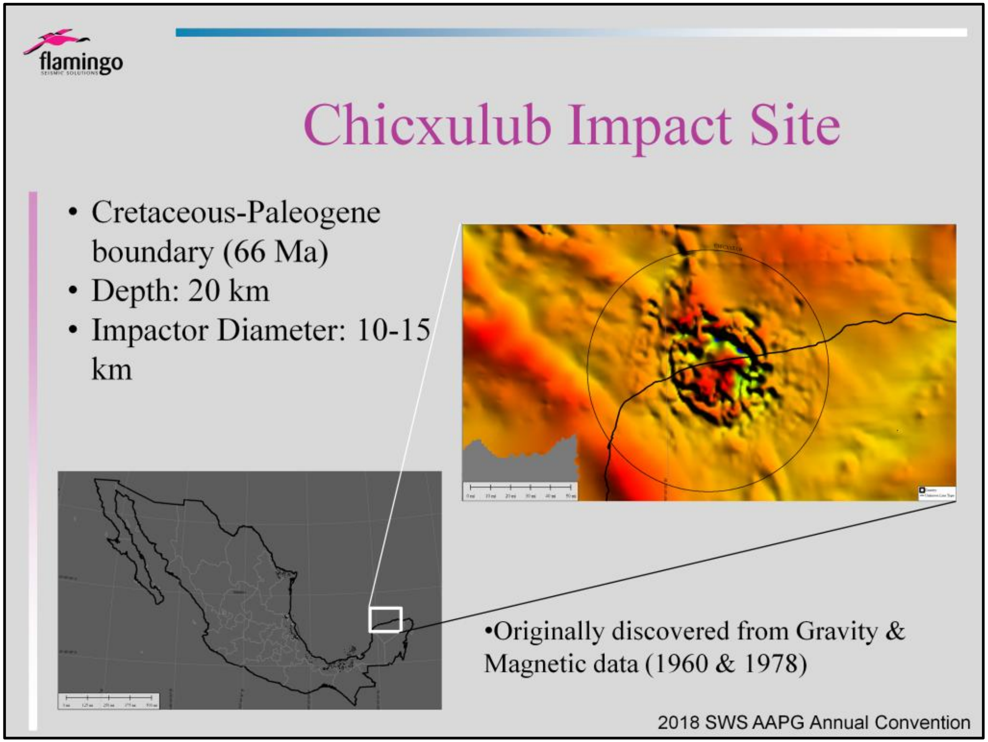
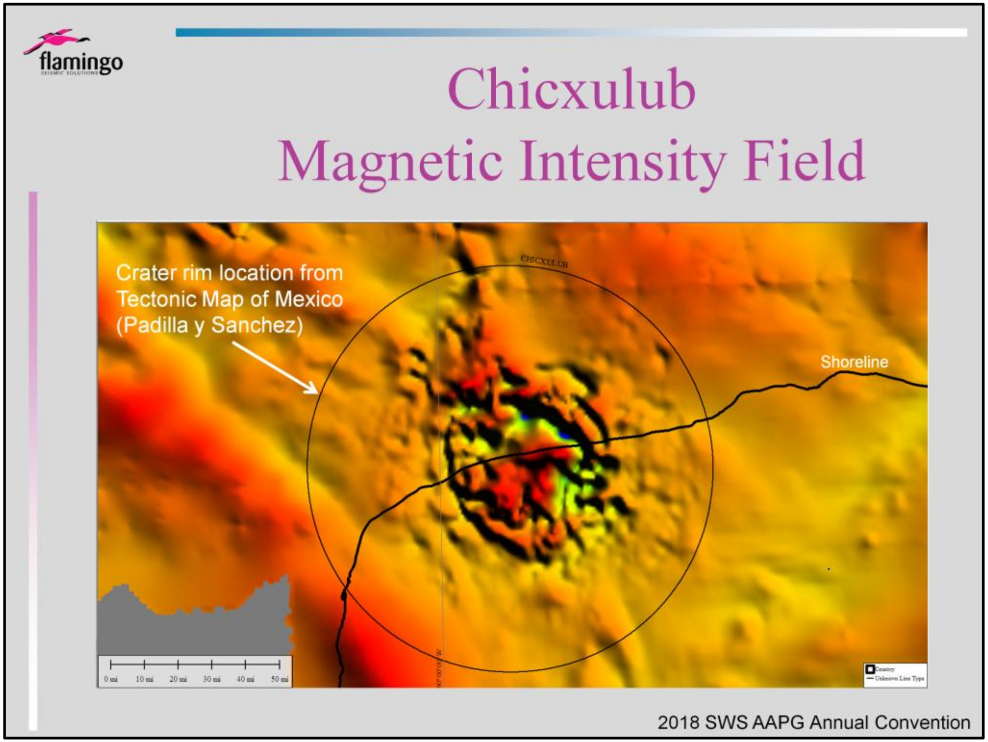
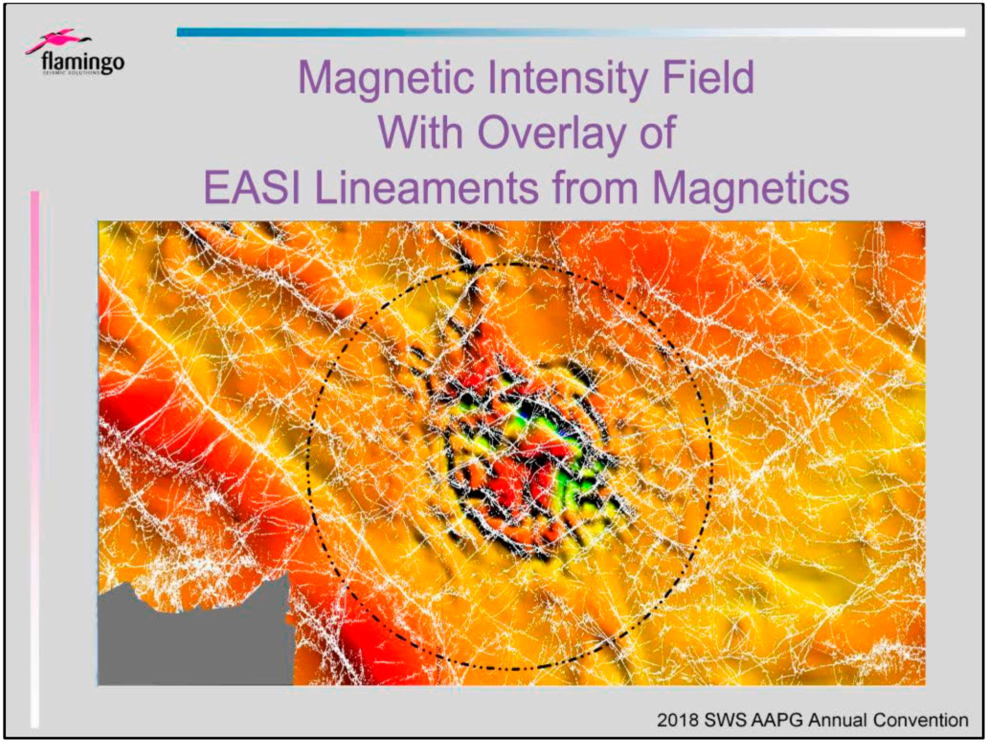


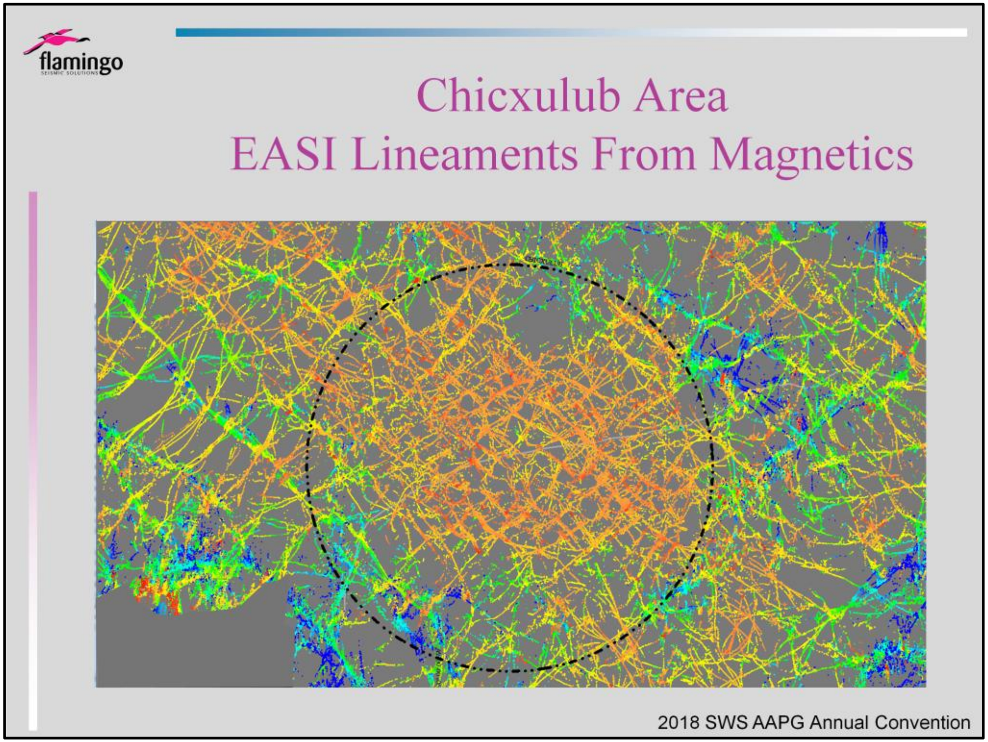
The Chicxulub crater is the site of a major meteor strike, identified as having created the marker between the Cretaceous and Paleogene periods, giving rise to global changes that killed-off the dinosaurs.
The impactor is estimated to have been 10-15 km in diameter, and impacted to a depth of 20 km. The crater was first discovered on gravity and magnetic data in the 1960’s (unpublished at the time) and again in the 1970’s.



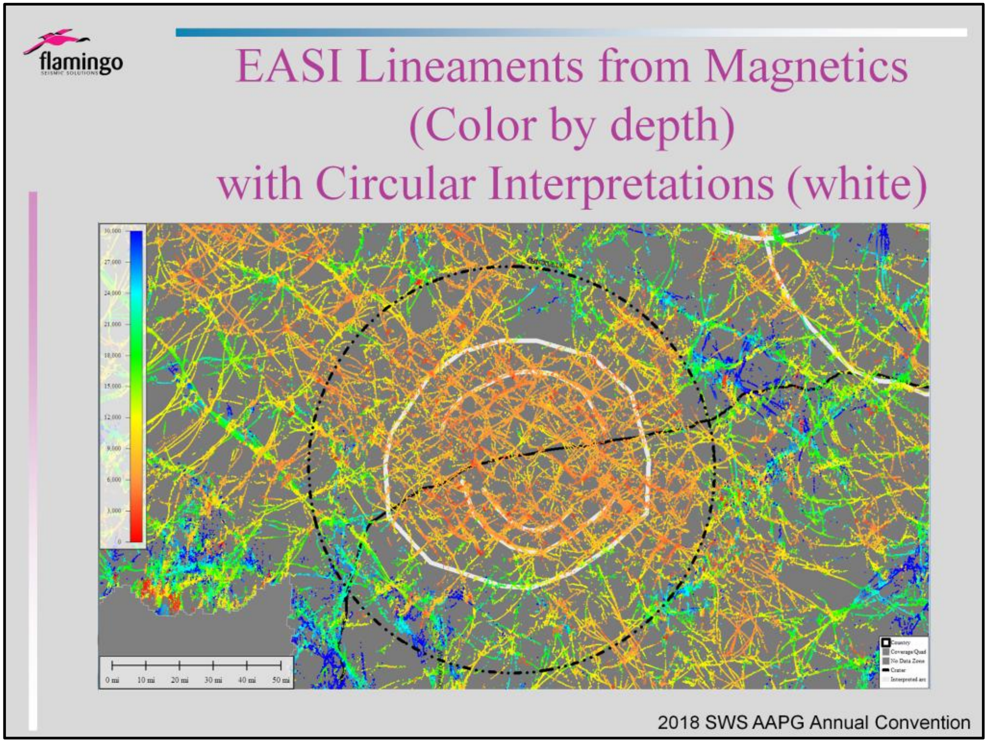
Looking at the magnetic field used for input to EASI, ring structures can easily be seen. The black circle is the crater rim location from Padillay y Sanchez. A “no data” zone can be seen in the southwest.



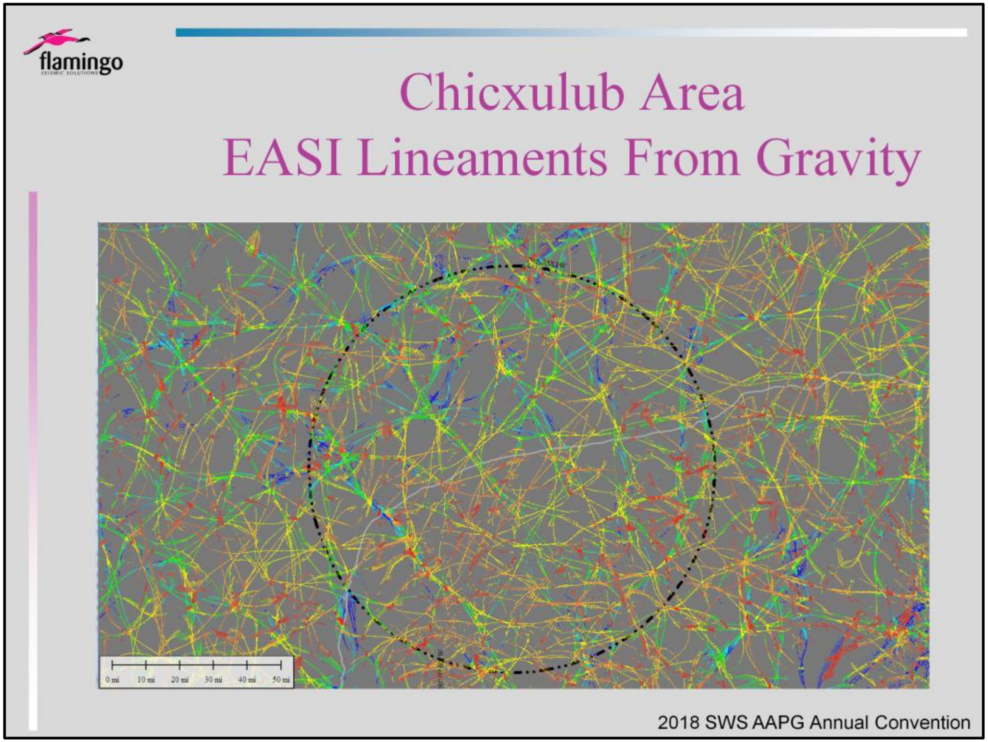
Overlaying the EASI lineaments (in white to be easily seen) on the input field, they can be seen to coincide with the features that are brought out by hill-shading the input data.



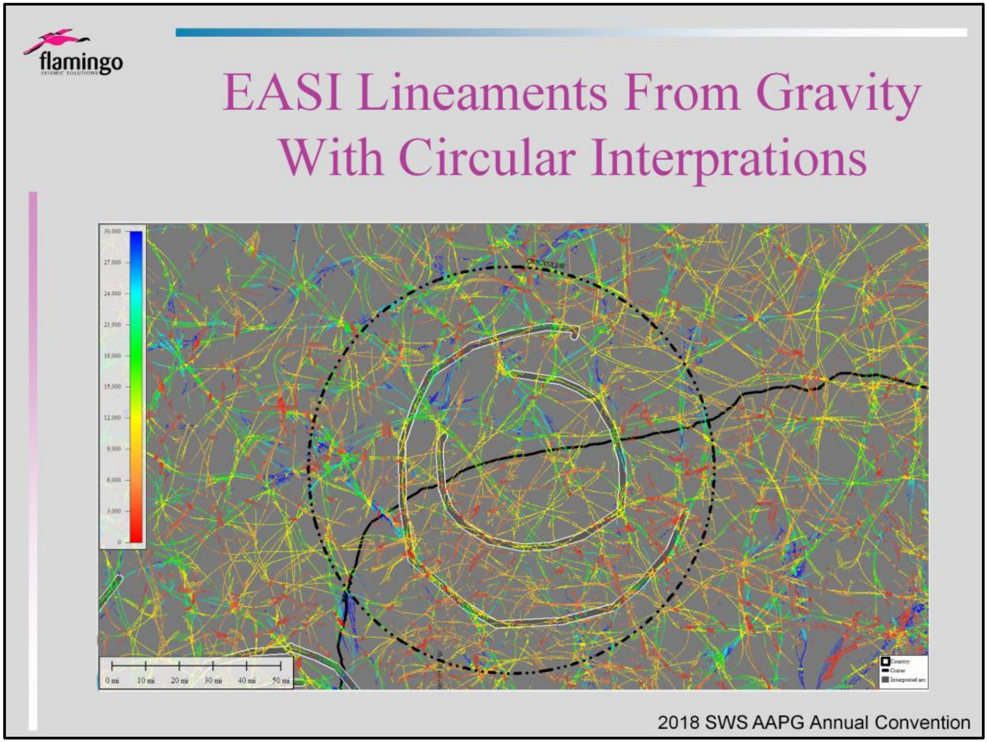
Showing the lineaments color-coded by estimated depth, we see a circular group of shallow lineaments (red) in the center of the crater.



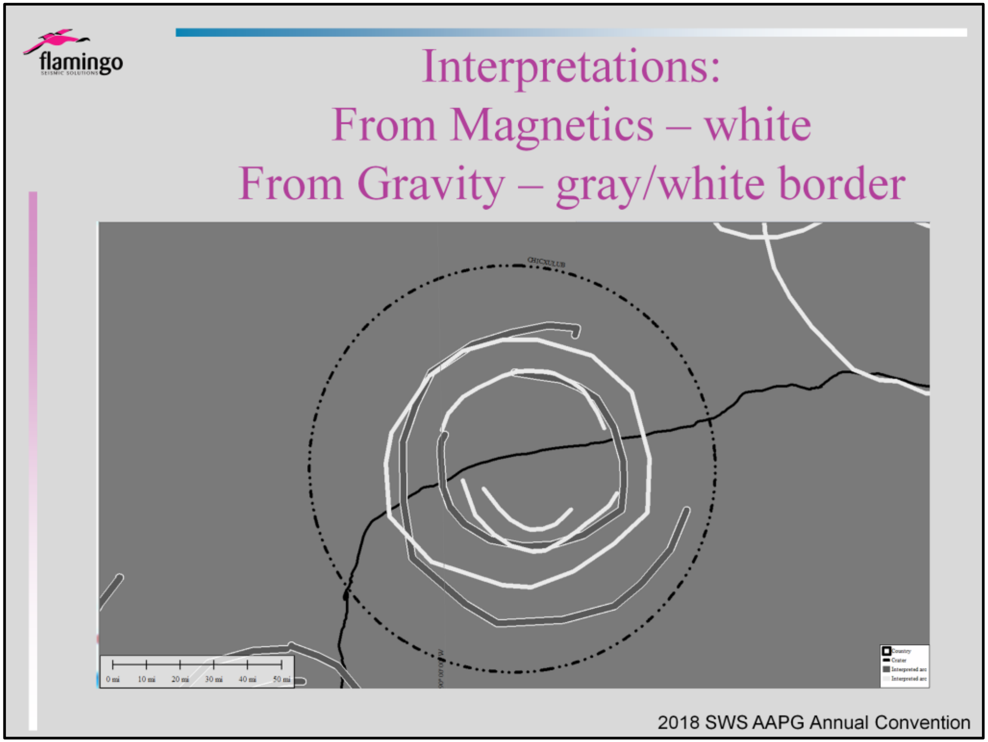
Here we have highlighted with white some of the circular features seen on the magnetic lineaments.



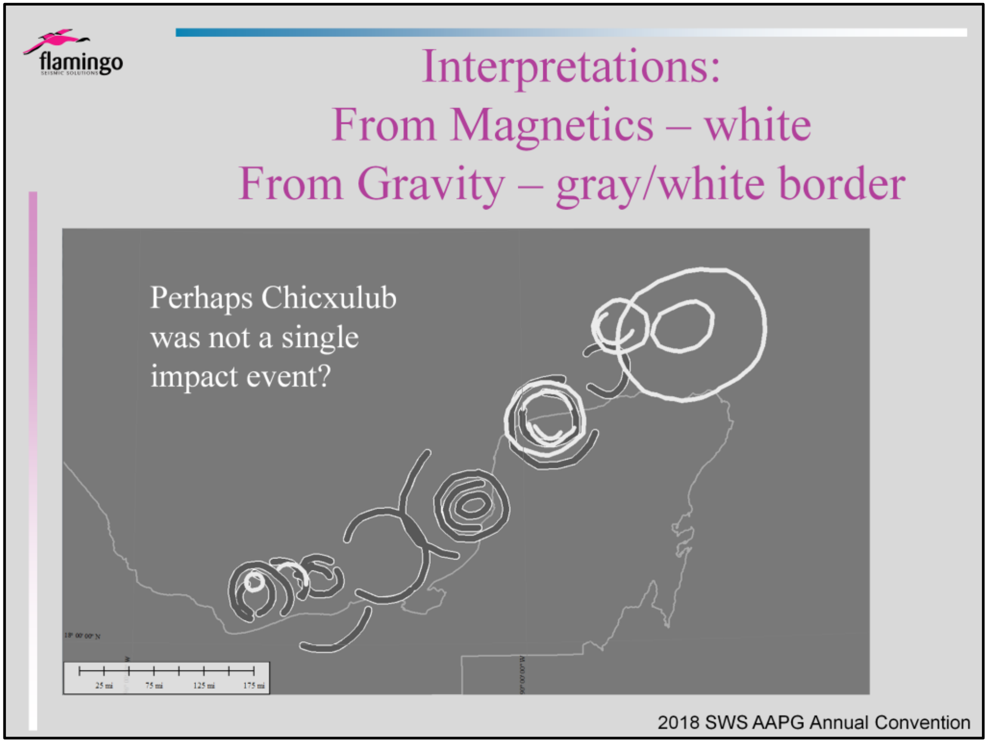
Gravity sees different features but also shows arcs within the crater.



Some of the arcs on the gravity lineaments have been highlighted with dark gray/white lines.



Overlaying the arc locations from gravity and magnetics we see definite agreement between the two.
Also seen are some other nearby arcuate features to the northeast and southwest.



Zooming out we can see a number of circular features detectable on both magnetics (where available) and gravity. This leads to the suggestion that Chicxulub might not have been a single impact event.
There is reason to believe this to be possible.

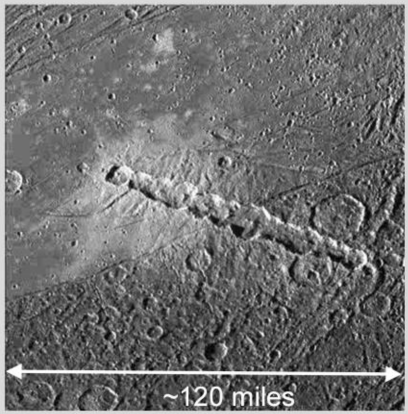
Example of multiple impact sites in close proximity

Hubble telescope image of Shoemaker-Levy 9
After fragmentation (1992),
Before impact on Jupiter (1994)

By NASA, ESA, and H. Weaver and E. Smith (STScI) -
http://hubblesite.org/newscenter/archive/releases/1994/26/image/c/ (direct link), Public Domain,
https://commons.wikimedia.org/w/index.php?curid=164667

Astronomers have noted chains of impact sites on moons and planets which were not well understood until the breakup of the Shumaker-Levy 9 comet in the early 1990's. The Hubble telescope captured remarkable images of the chain of fragments as they neared impact on Jupiter in 1994.

Another example:



Chain of impact craters on Jupiter's moon Ganymede

By Credit: Galileo Project, Brown University, JPL, NASA - from http://antwrp.gsfc.nasa.gov/apod/ap011215.html (page in NASA Photojournal), Public Domain, https://commons.wikimedia.org/w/index.php?curid=973137

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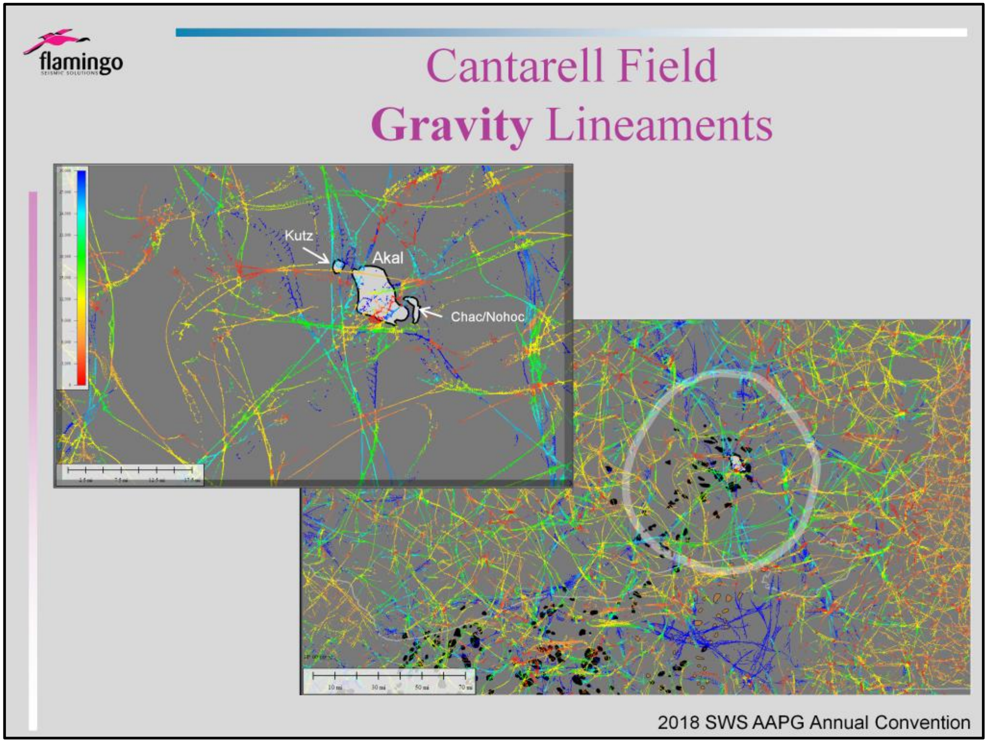
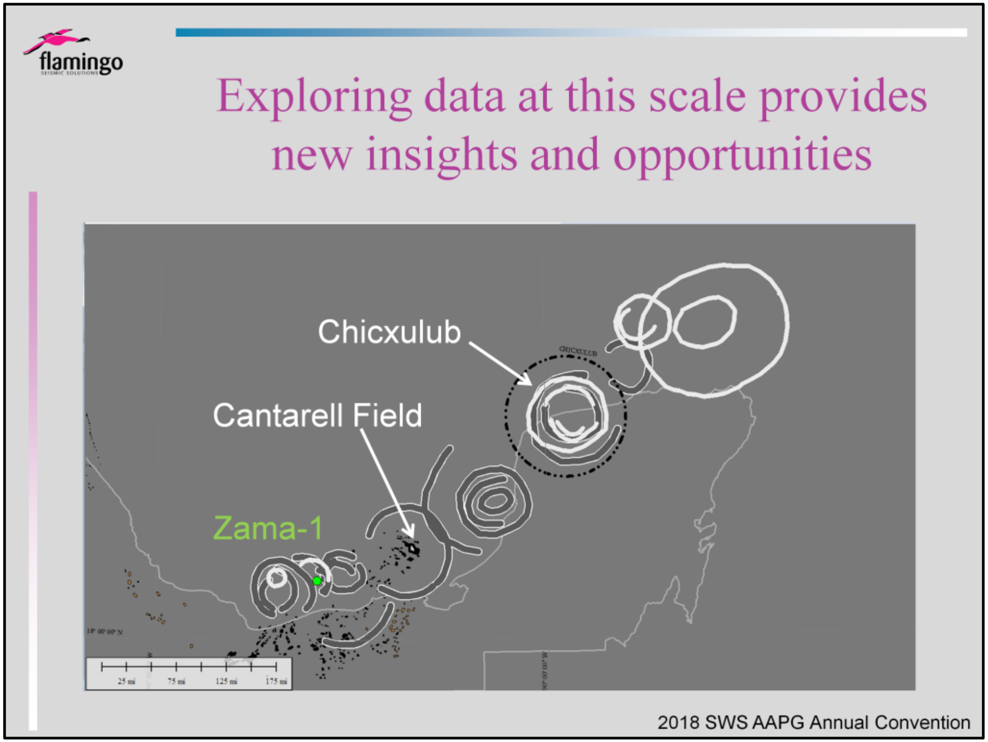
Another example from Jupiter's moon Ganymede shows a chain of impact craters. These chains have been seen enough that astronomers have designated them catena.

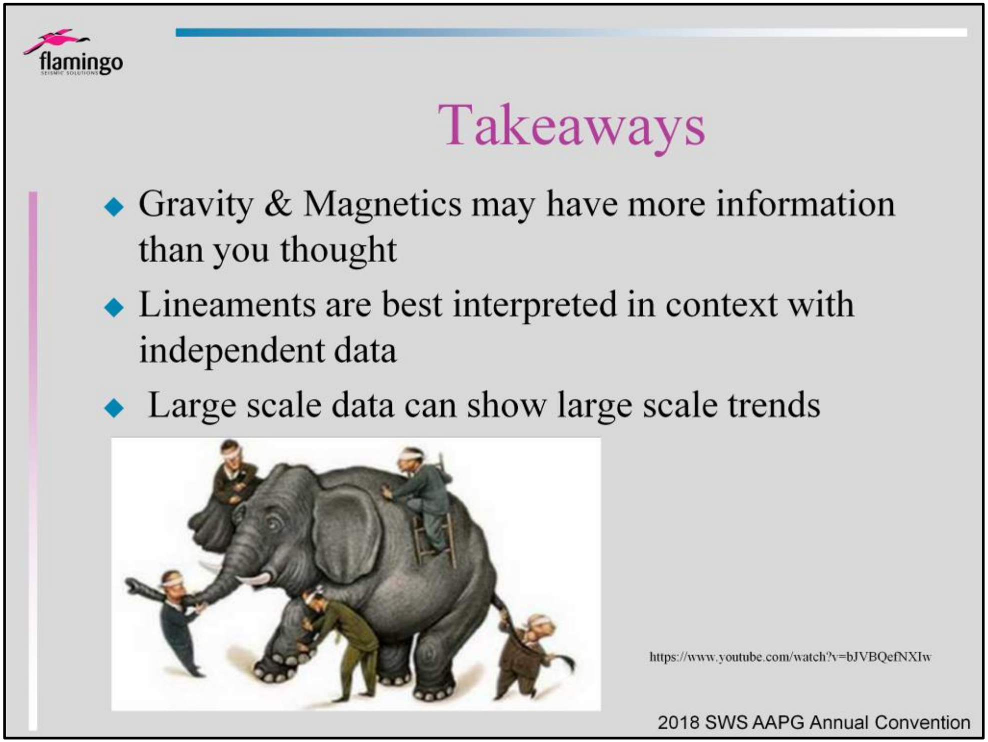


Now if we revisit the earlier images of the Cantarell field area, we see one of these rings encircling the Cantarell complex.

While these lineaments provide useful insight by themselves, they are best utilized with independent sources of data such as seismic, seepage, or (as we have seen here) production data.



Here we see some of the circles and arcs that have been identified on the lineaments in relation to producing fields and the Zama-1 discovery.
(Note there is a no-data zone for public magnetic field data in the area with no magnetic rings)



We have seen that looking at data on the large scale available with regional potential fields grids can show remarkable detail, as well as making it possible to see features that might not otherwise be recognized. As the parable of the blind men and the elephant reminds us, it is important to look at all available data in context and see the "big picture".

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   "Serendipity: A search for lineaments finds impact craters?."
   The Leading Edge, 36(5), 431–436.

For more on EASI lineaments and its character at other impact sites, a paper in The Leading Edge from May 2017 examines several in North America [7].