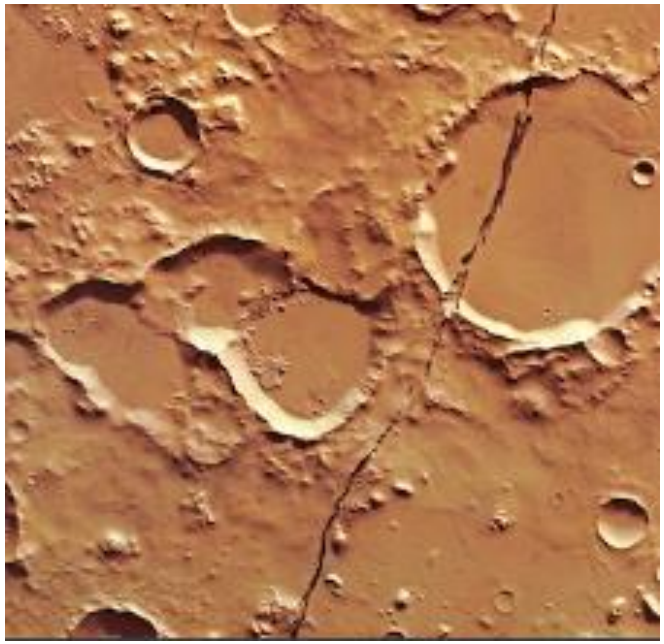
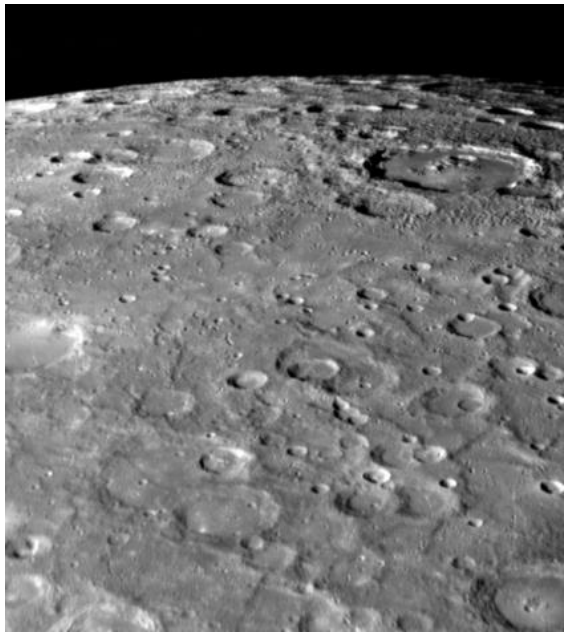
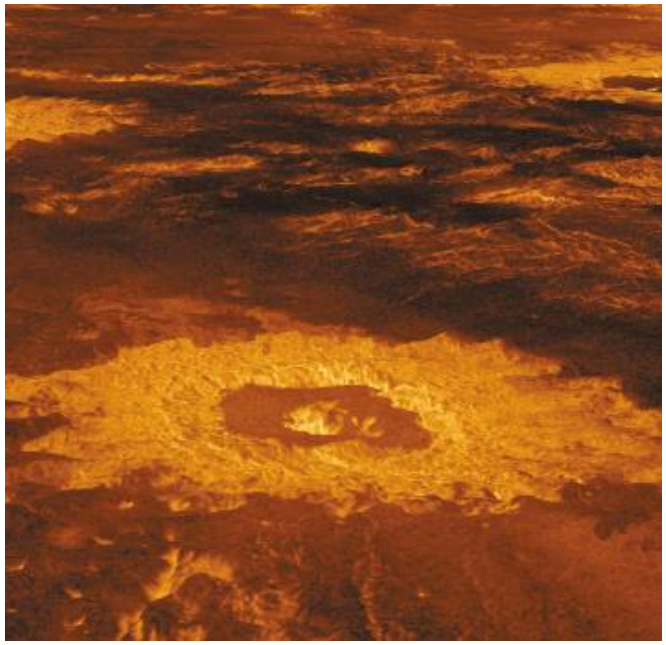
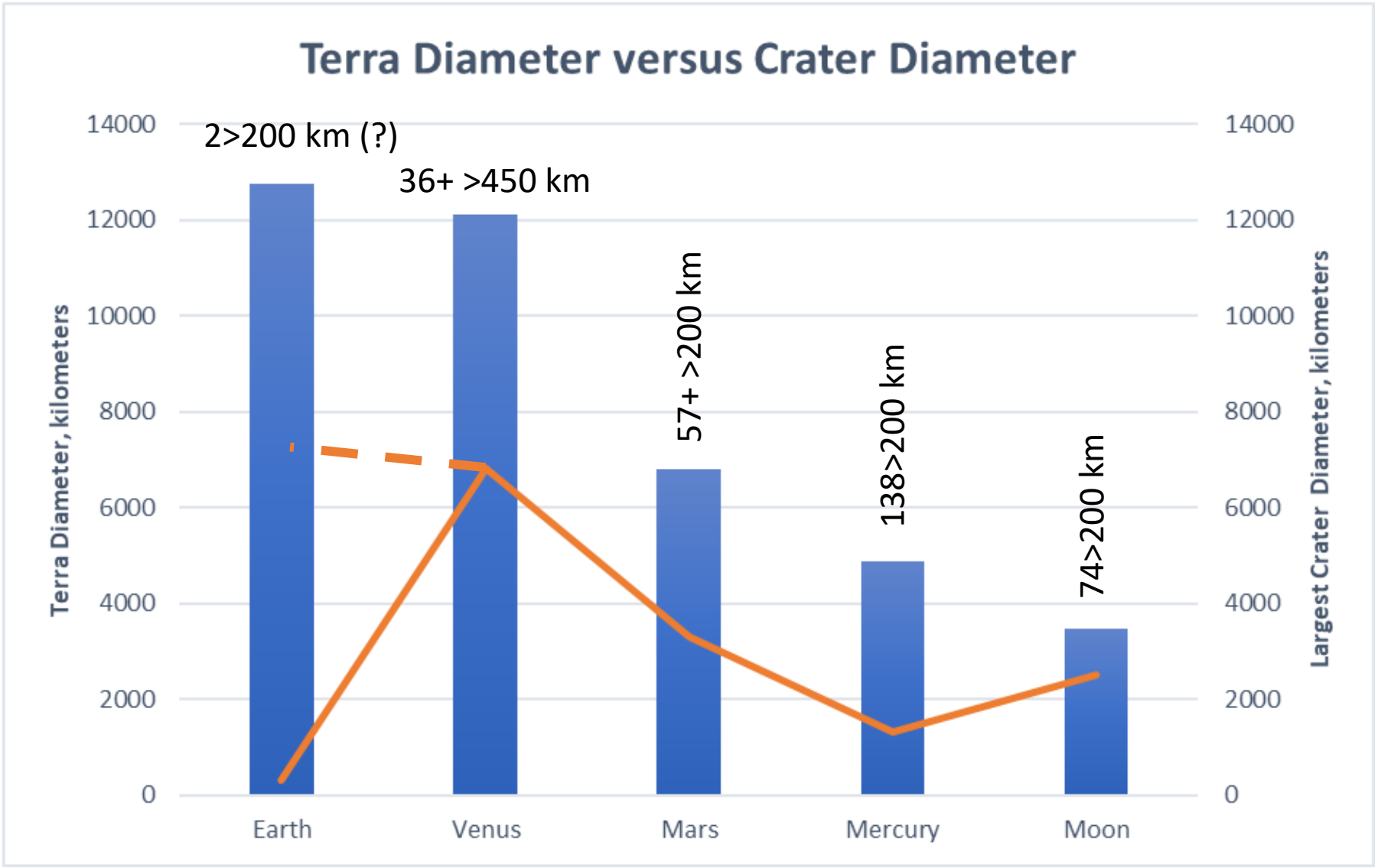




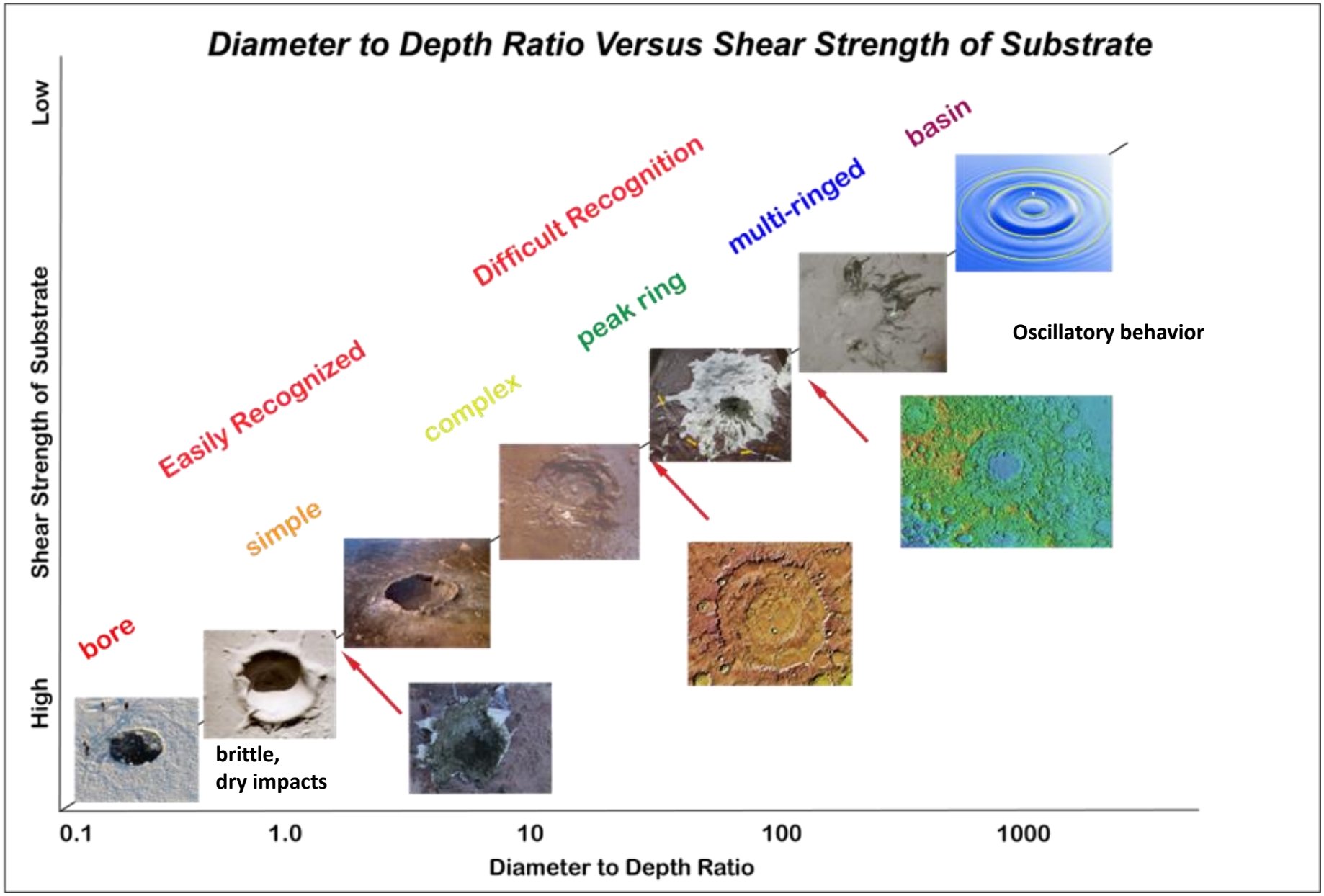


The most common geological structures in the terrestrial universe = impact craters

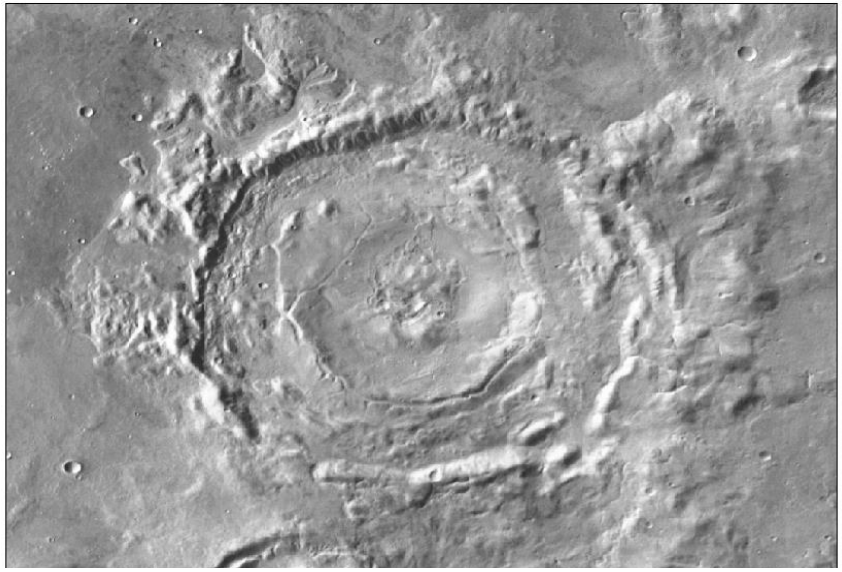
# What Are the Abundances of Large Impact Basins in Our Universe?



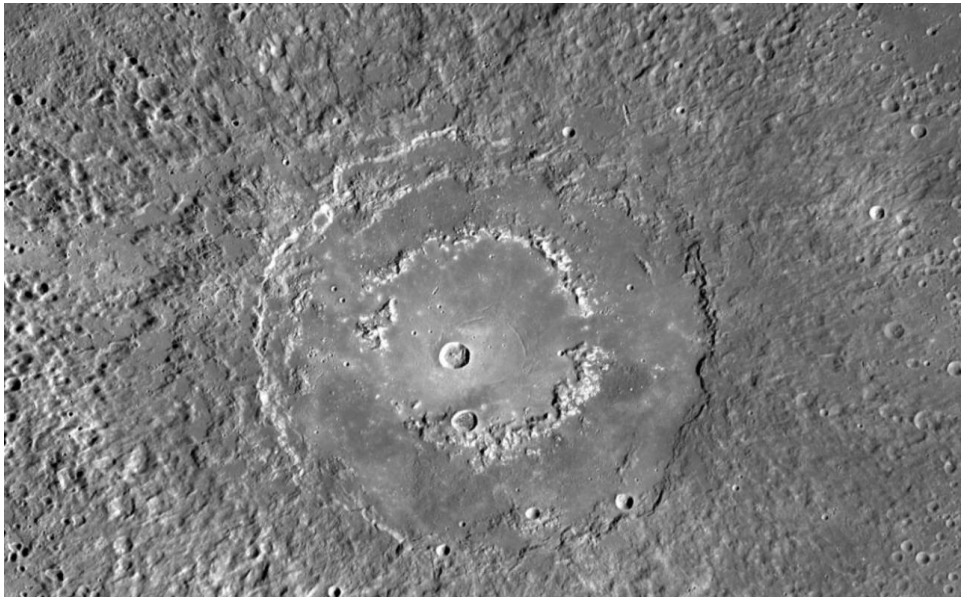
# What Do They Look Like?



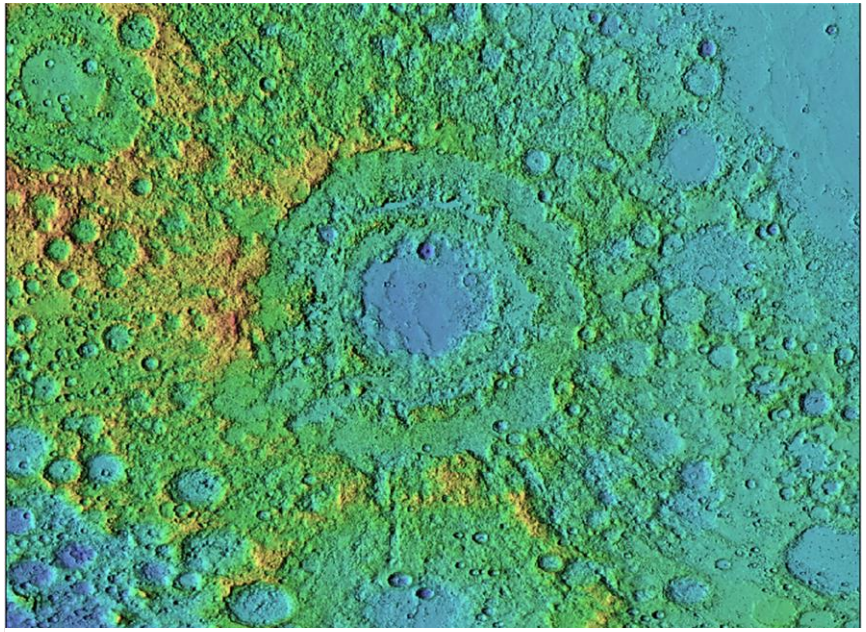
Simple crater, Earth, **1200 meter** diameter



Complex peak ring or multi-ringed crater, Mars, **50 km** diameter



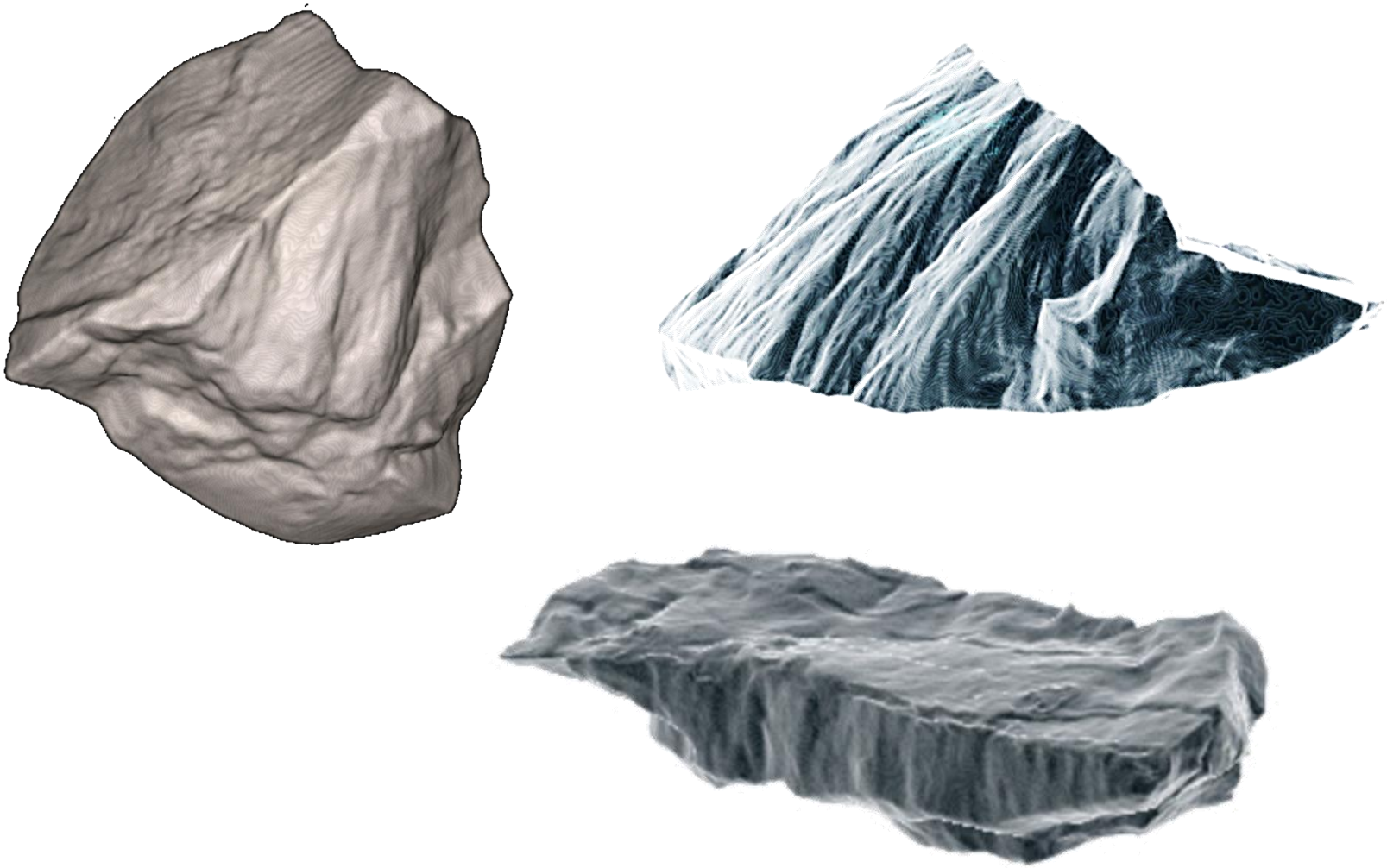
Raditladi peak-ring basin, Mercury. Mercury dual imaging system (MDIS) Crater diameter is **258 km**. NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washingston, 4/16/2015.



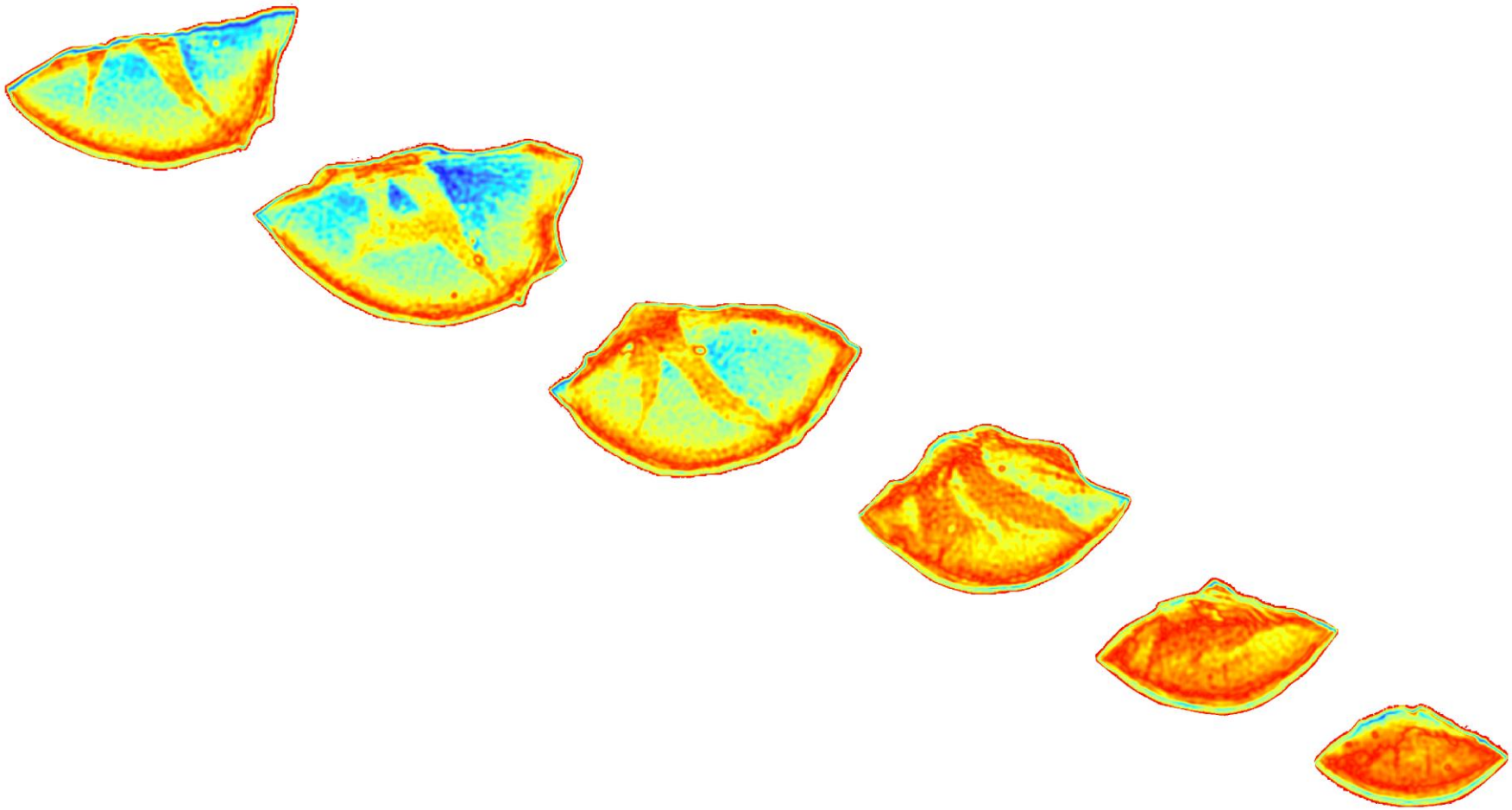

Mare Orientale multi-ringed crater basin. Innermost ring is 340 km diameter, outer rim is **962 km** diameter.

# Shattercones: Mesoscopic Proof of Impact, Diagnostic

# CT-Scans of Shatter Cones



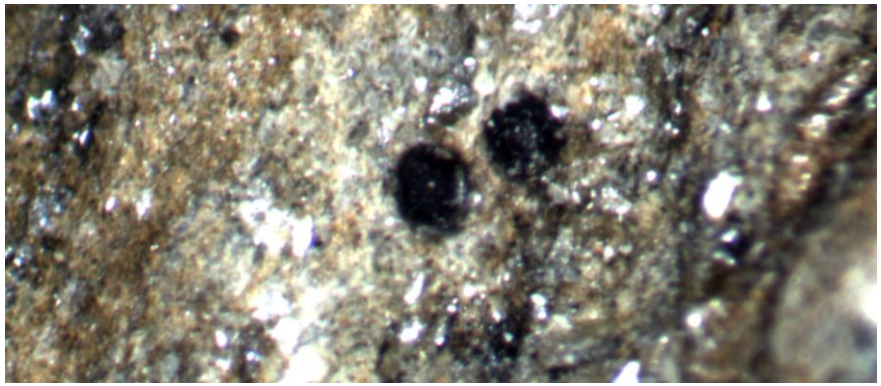
# Evolution of a Shatter Cone: CT-Scans



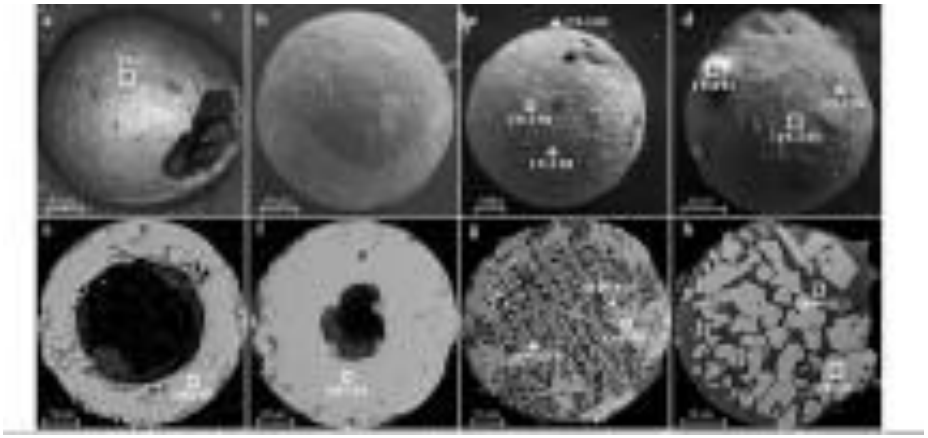

# Breccias Diagnostic

**Top row: UL: Ordovician polymict breccia, Glover Bluff, WI; Bee Bluff breccia, TX; Crooked Creek, MO; and Glover Bluff. Then left: Devonian breccia, Decaturville Crater, MO.**

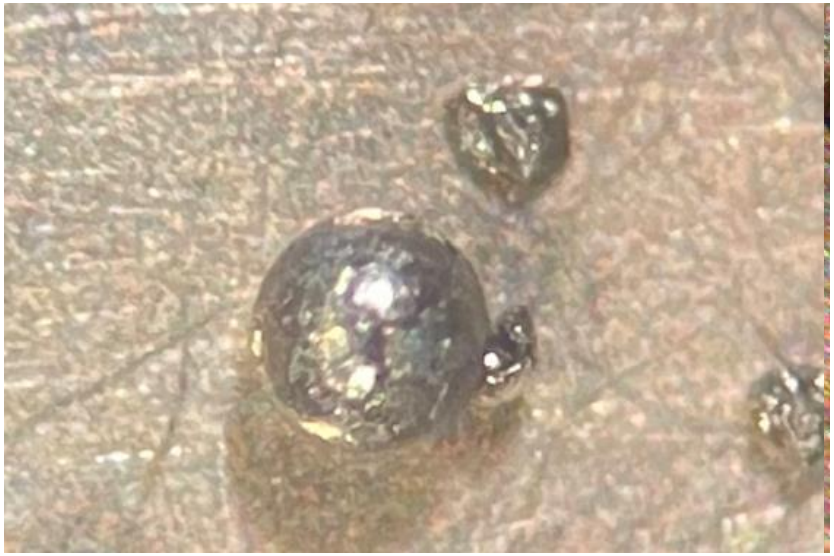
# Metallic Spherules



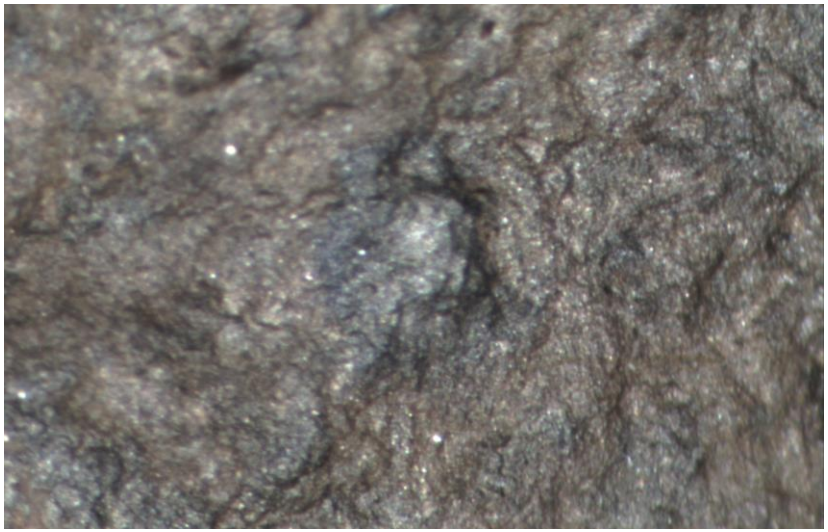
Mt. Wick, Alaska, black micro-spherules in dirty marble. Spherules are 350 microns (0.35 mm) diameter. These rocks are caught up in soft-sediment gravity folding down the transient crater walls



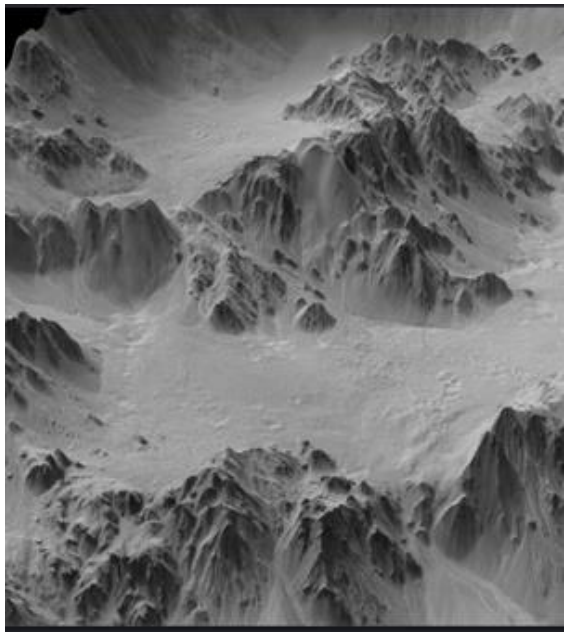
Origins of microspherules from the Permian-Triassic boundary event layers in South China (Zhang, et. al., 2014). Scale bars 10-40 microns.



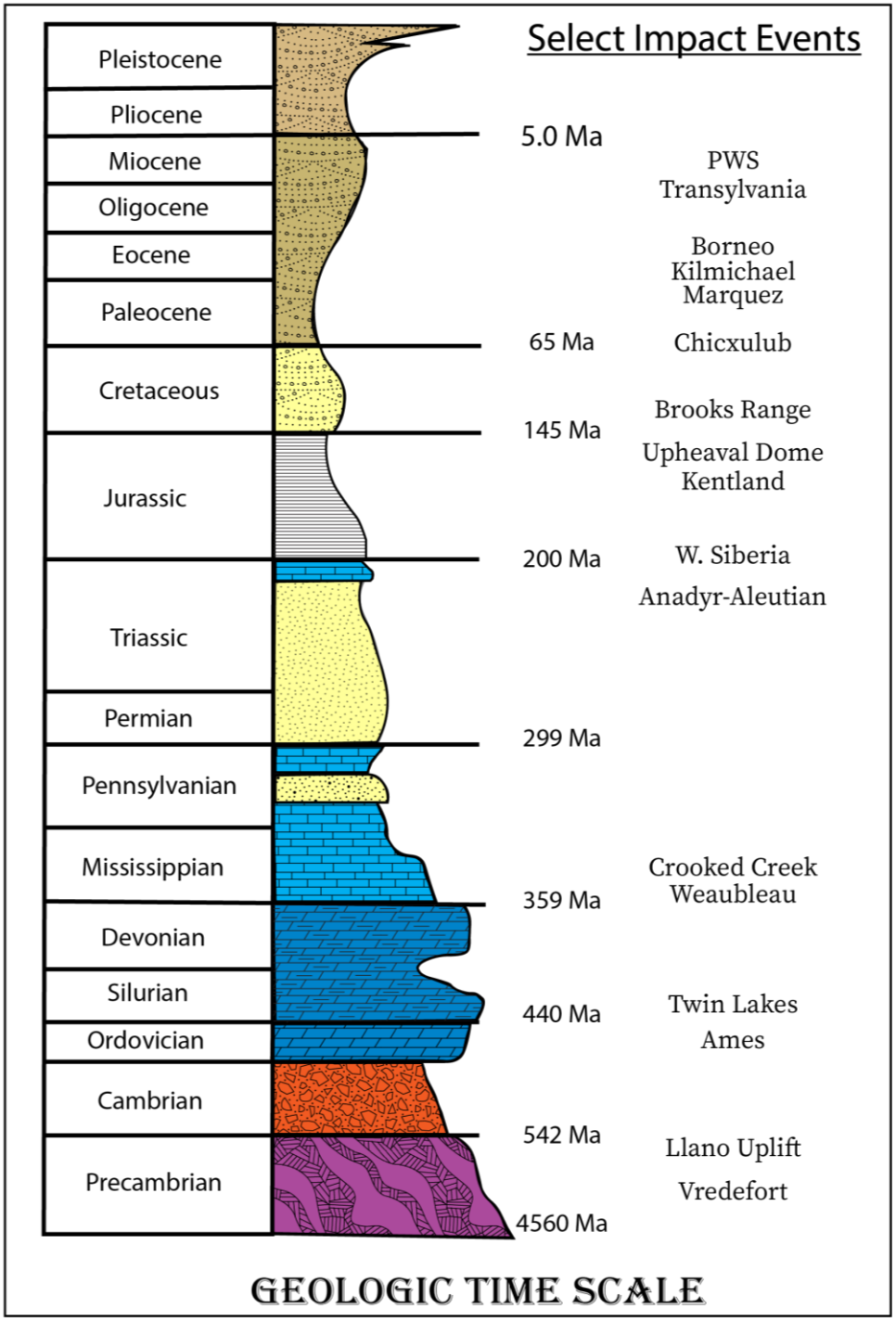
Metallic spherule measures 0.25 mm diameter. Upper Beluga Formation, 5.7 Ma, from test well near Anchor Point.



Metallic spherule measures 0.5 mm diameter. Oneonta Formation clay-rich shales. Panther Mountain crater, west of Shandaken, New York.



Virtually all arcuate mountain ranges in our terrestrial Solar System are rims of large impact basins.




**Prince William Sound (PWS):** 750 km diameter. Late Miocene, 5.7 Ma.

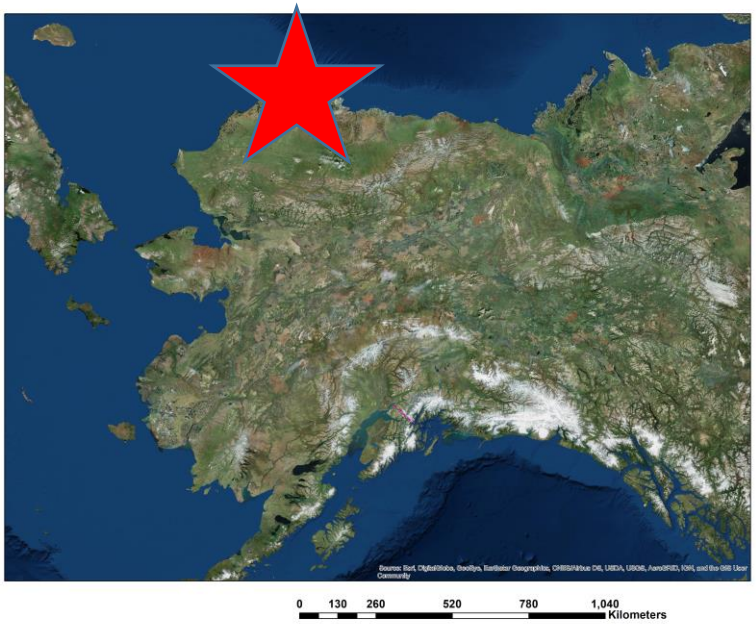
**Avak Astrobleme**: 12 km diameter. Cretaceous Turonian (91-94 Ma) age (Banet & Buthman, 2006).

**Brooks Range Asteroid Impact**: 2550 km diameter. Lower Cretaceous Crater structure formed 120 Ma, during the Lower Cretaceous.

**Anadyr-Aleutian**: 3190 km diameter. Upper Triassic

**Council Structure**: 97 km diameter. Structure formed during the Ordovician.

# Geologic Time Scale & Impact Craters on Earth

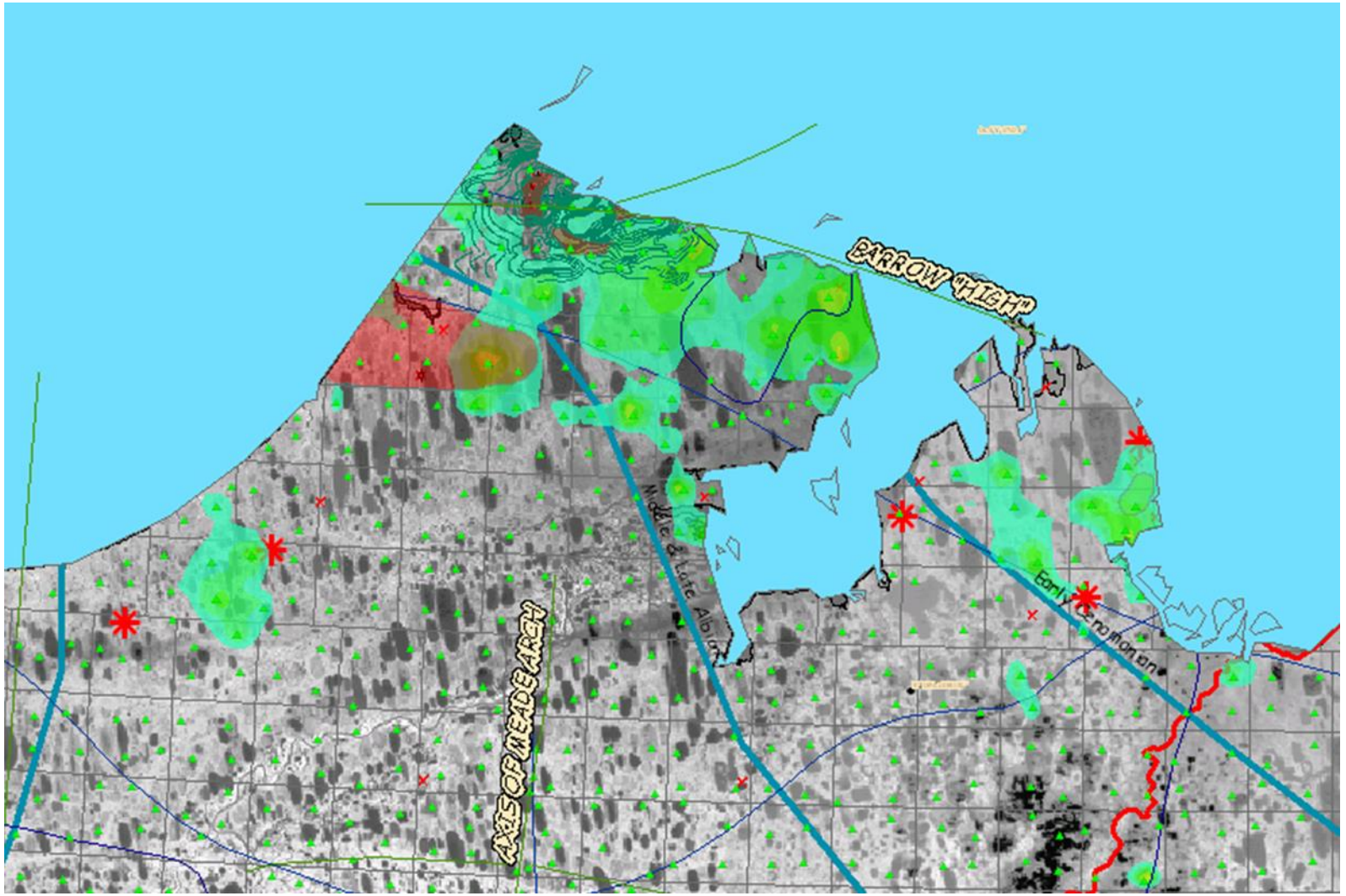



*Turonian*

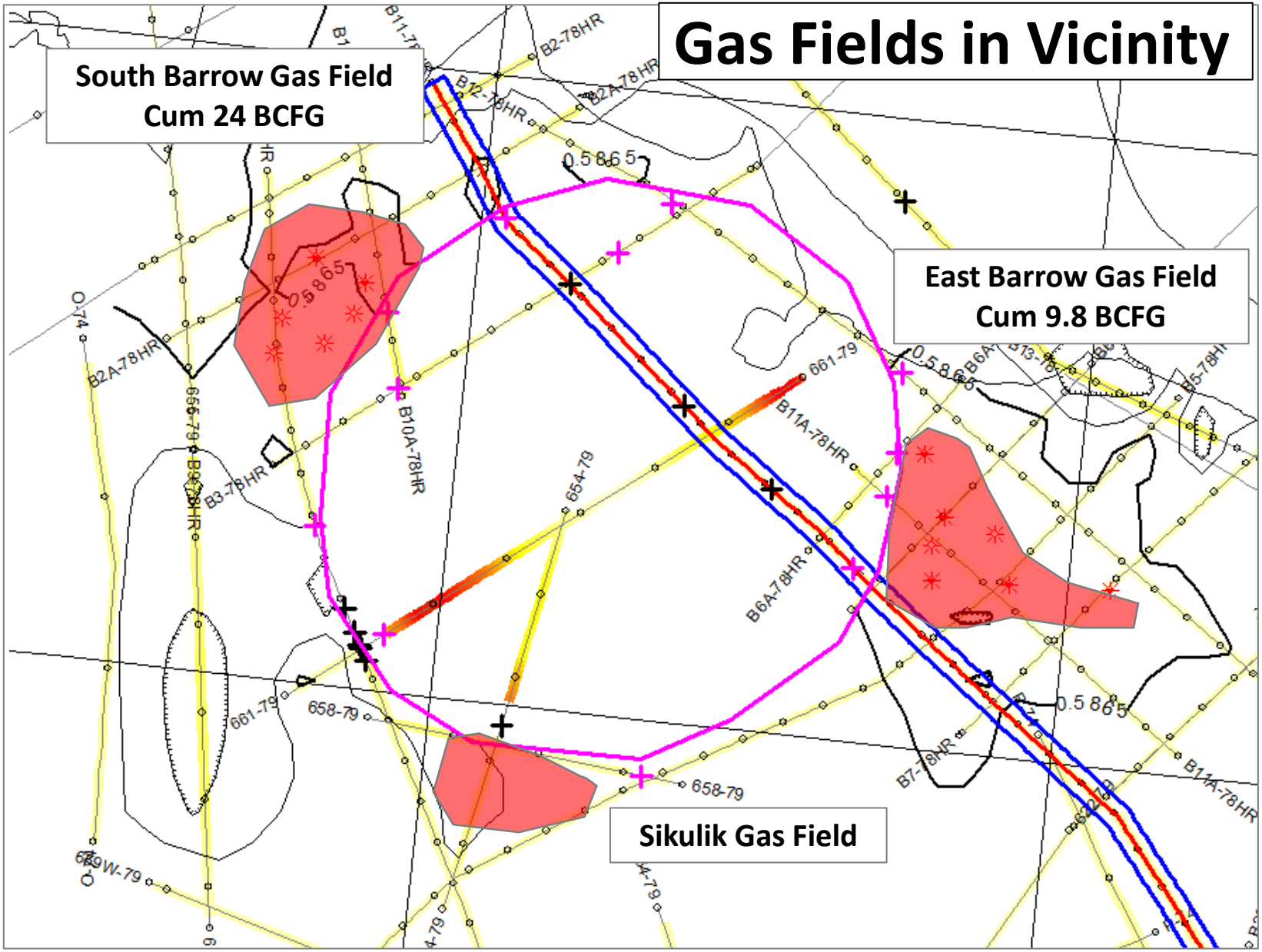
# AVAK ASTROBLEME

*Diagnostic: multiple sets of PDF's in quartz, & shatter cones.*

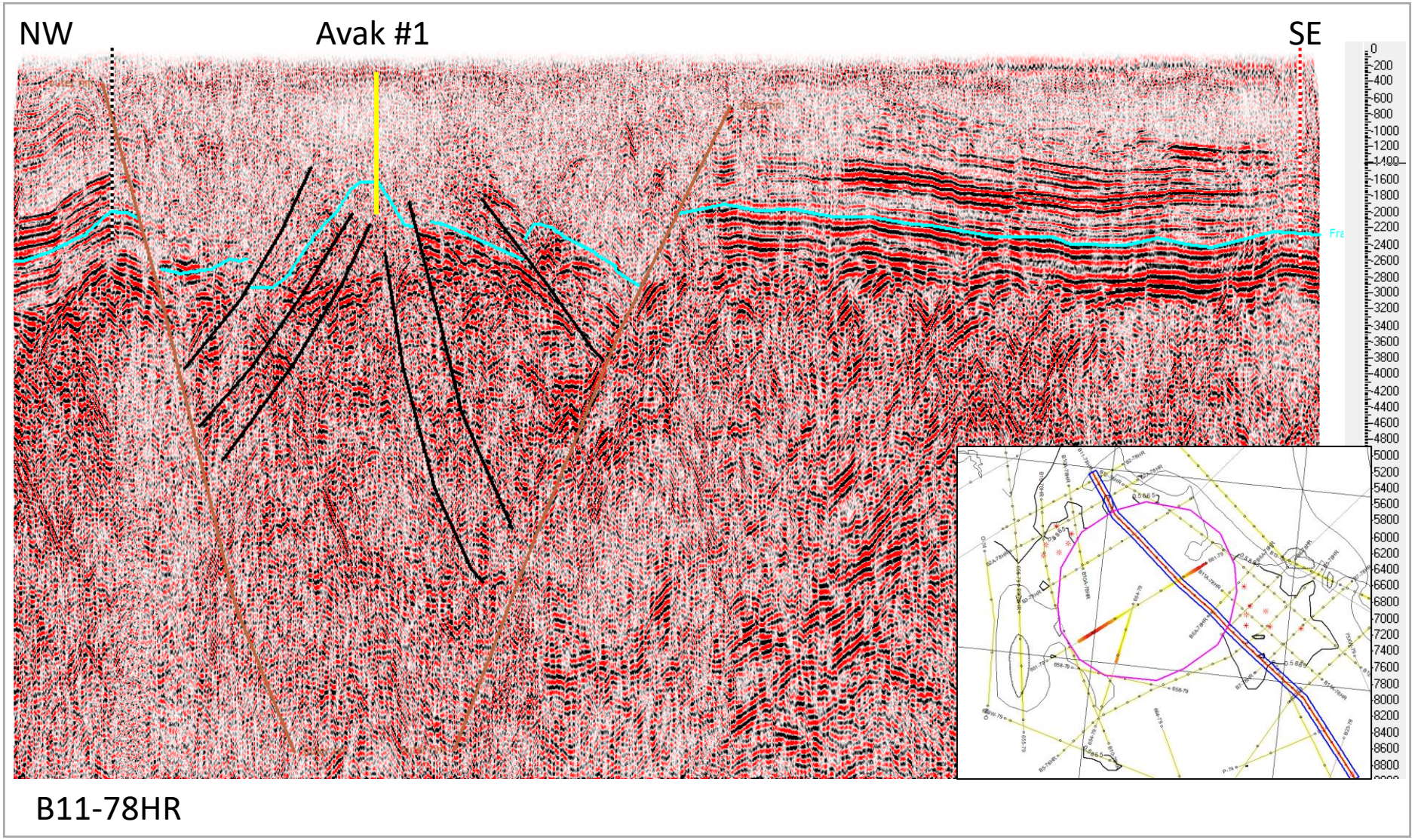
# NURE Fe-Ni Concentrations at Avak, AK

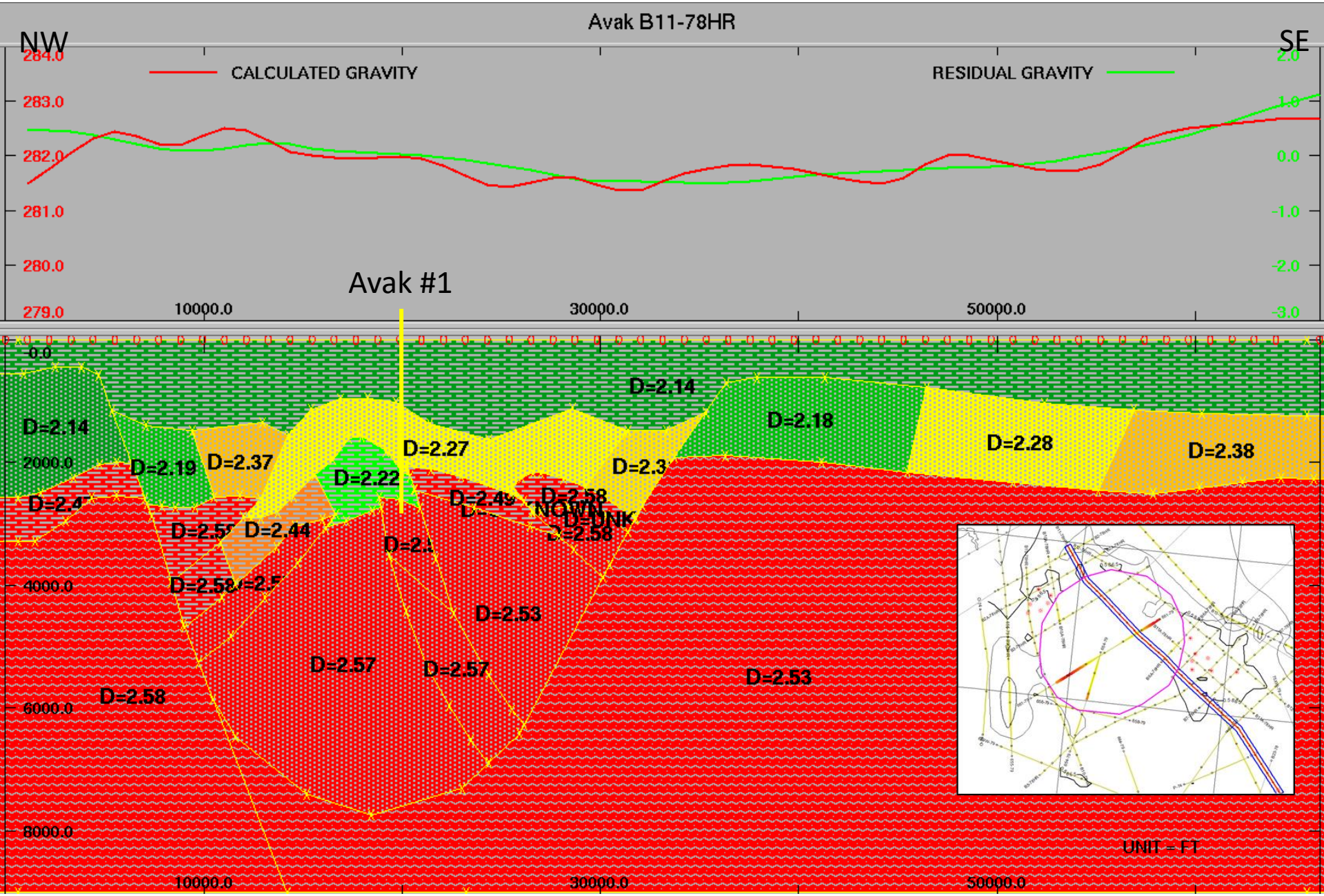



*Buthman & Banet, AGS-AAPG Conference, 2006*


Gas Fields in Vicinity
South Barrow Gas Field
Cum 24 BCFG
East Barrow Gas Field
Cum 9.8 BCFG
Sikulik Gas Field
5 km
12 km diameter
~250 m dia. iron bolide
91-94 Ma

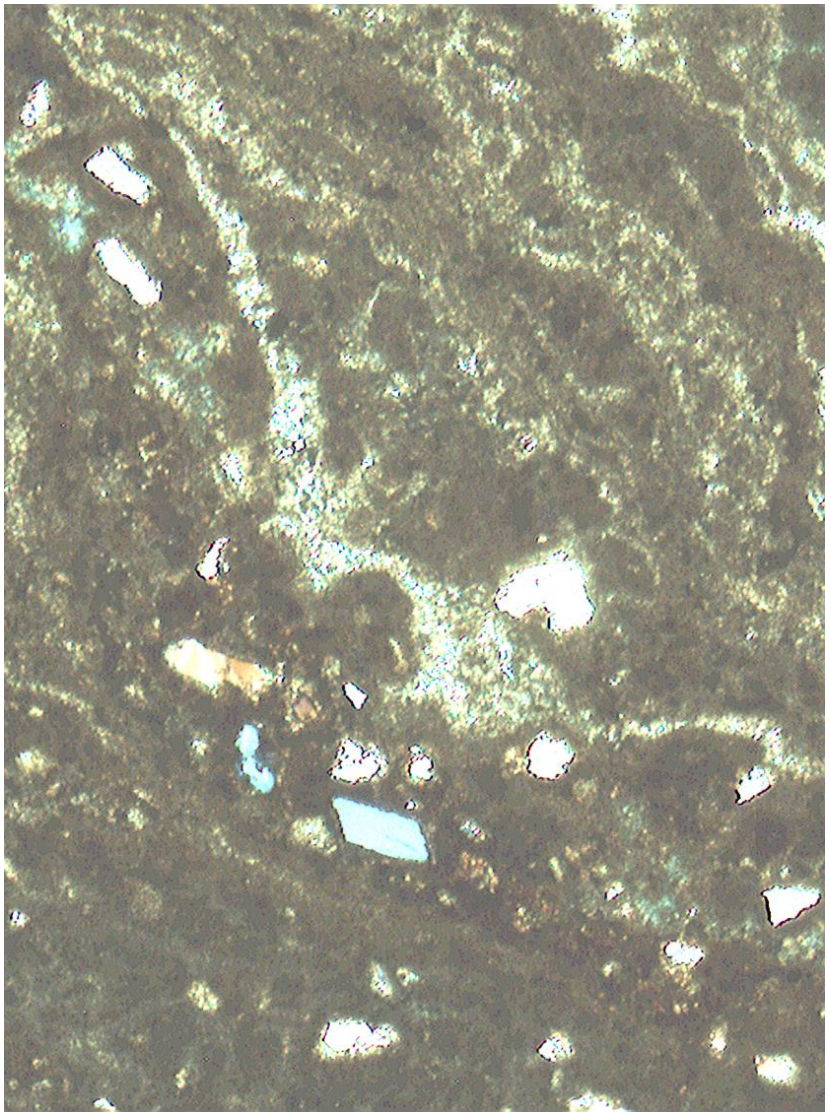
# Avak Astrobleme 2D Seismic




Avak B11-78HR
NW
SE
CALCULATED GRAVITY
RESIDUAL GRAVITY
284.0
283.0
282.0
281.0
280.0
279.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
10000.0
30000.0
50000.0
Avak #1
0.0
2000.0
4000.0
6000.0
8000.0
D=2.14
D=2.19
D=2.37
D=2.27
D=2.22
D=2.3
D=2.18
D=2.28
D=2.38
D=2.44
D=2.53
D=2.57
D=2.58
UNIT = FT

B11-78HR

# Flow Structures Meteor Crater (L) and Avak (R)

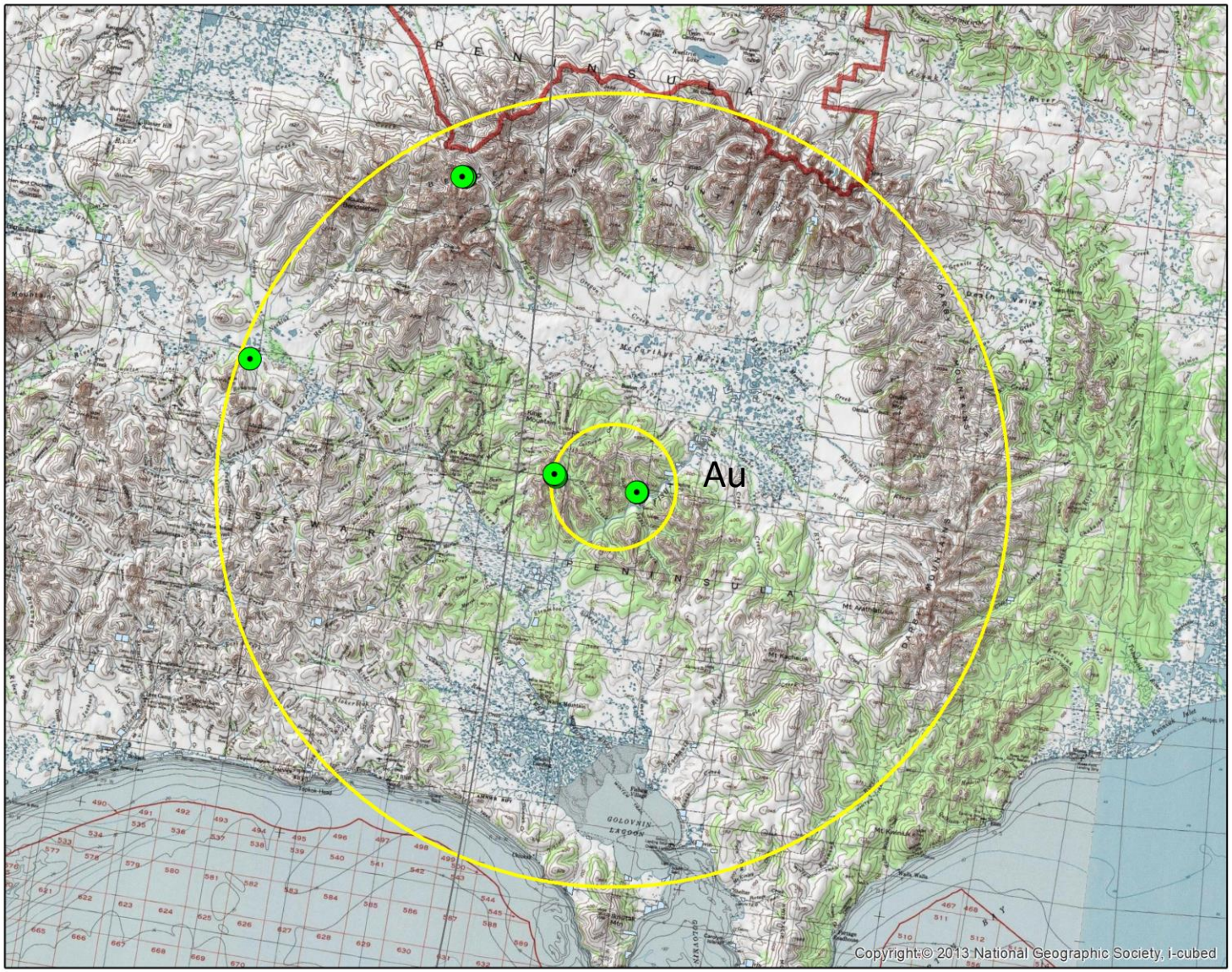


*Avak "proven" category because of multiple sets of PDFs in quartz, & shatter cones.*


*Ordovician*

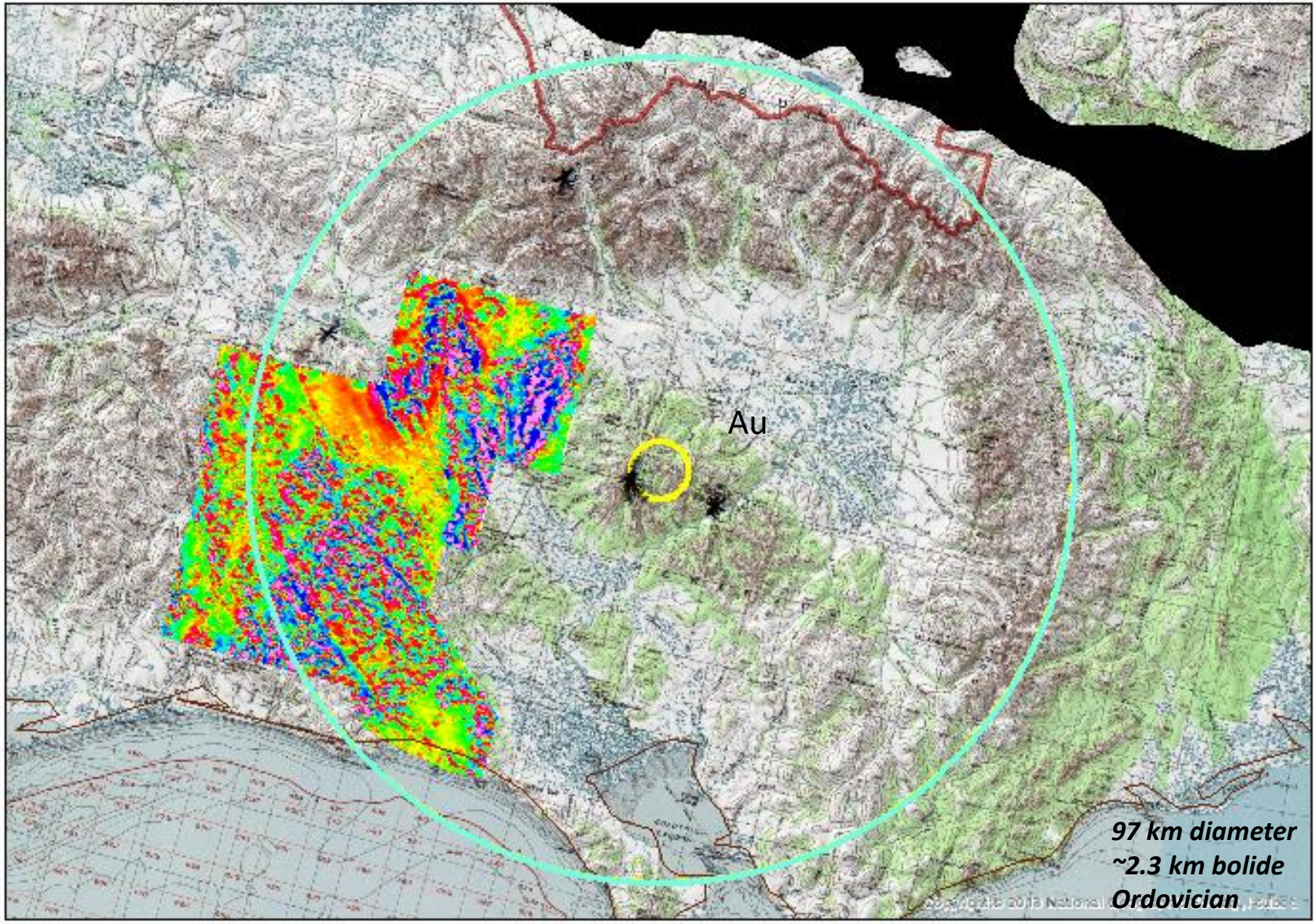
# COUNCIL, NOME

# Council Alaska Field Topographic Map

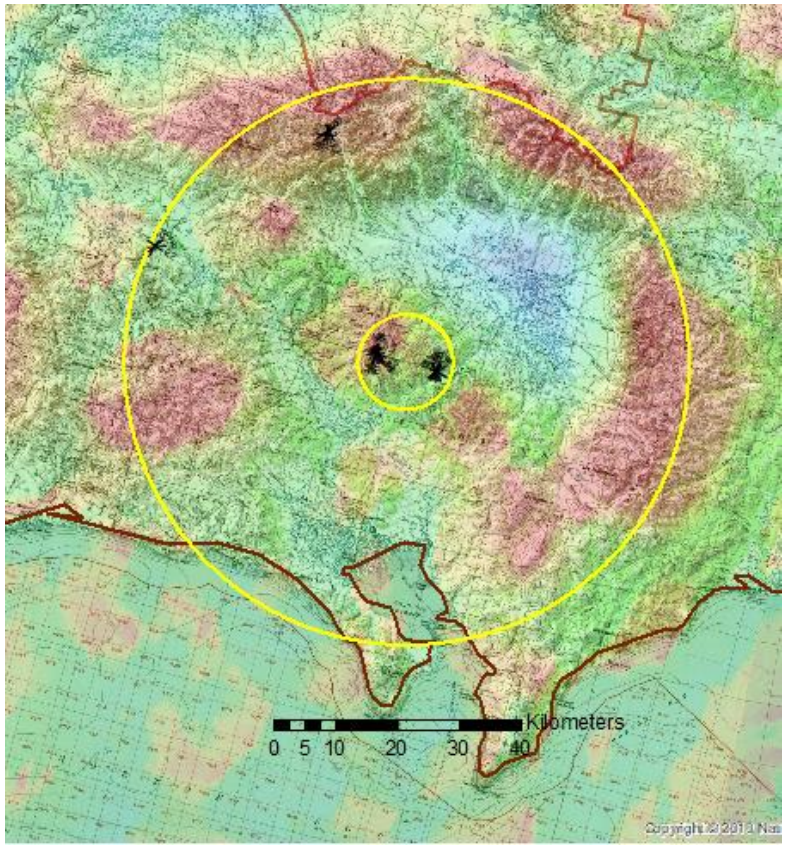



***97 km diameter***
***~2.3 km bolide***
***Ordovician***

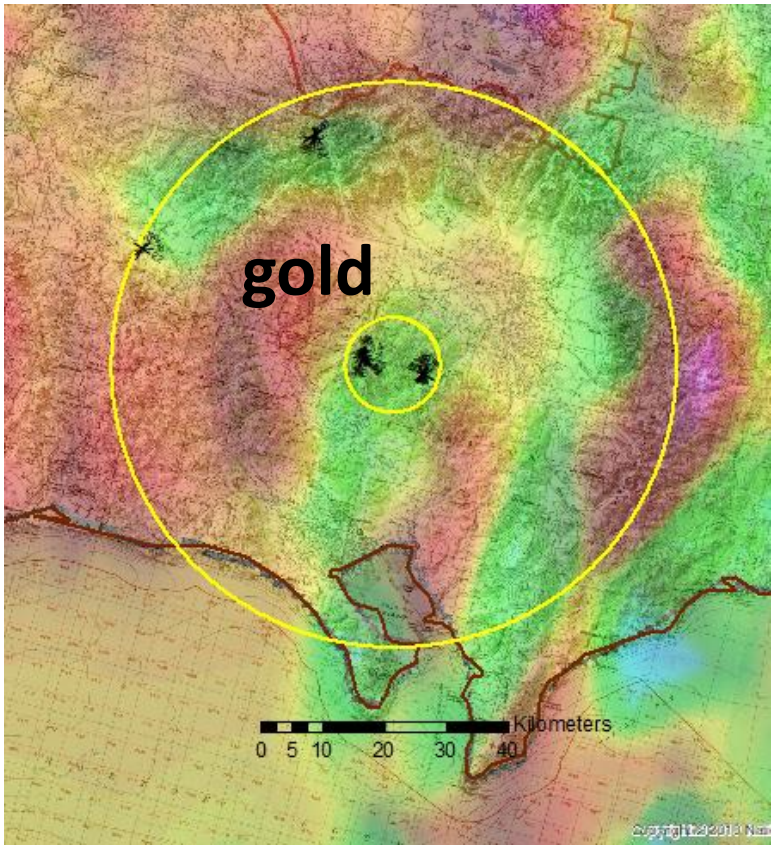
# With High-Resolution Magnetics



# Council Alaska Gravity & Magnetics

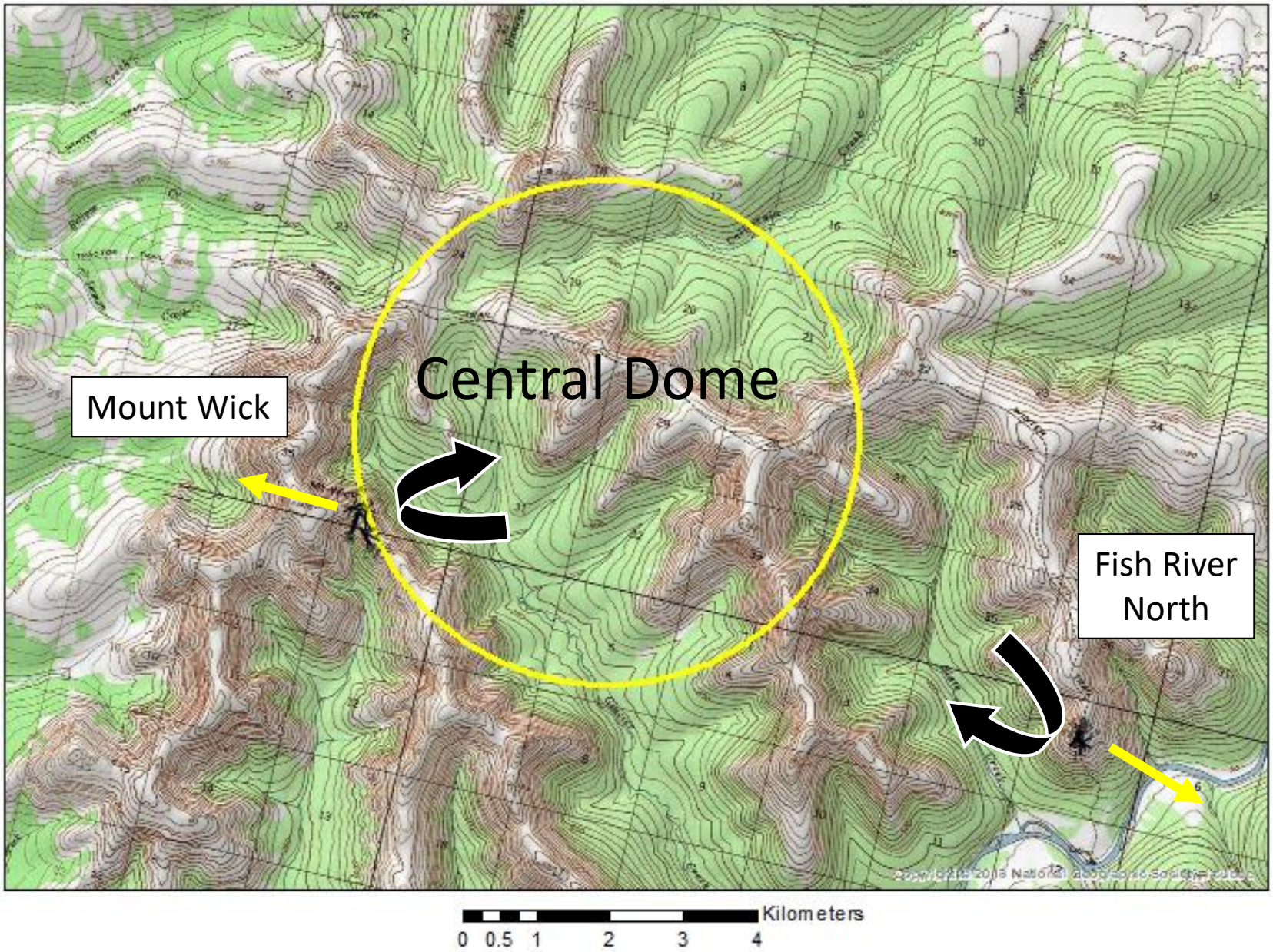



Sandwell 23 free air gravity

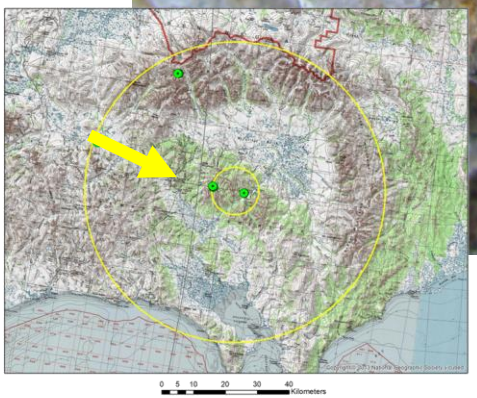



RMI magnetics, UC 4 km, E-mag 2

# Central Dome Field Stops



# East-Pointing Un-striated and Striated Cones,



Un-striated cones, Mt. Dixon

Glover Bluff in situ shatter cones

# Council Findings

Mt. Wick and Fish River North = demonstrate central dome.

Radial fold axes of recumbent folds at Mt. Wick and the North Fish River.

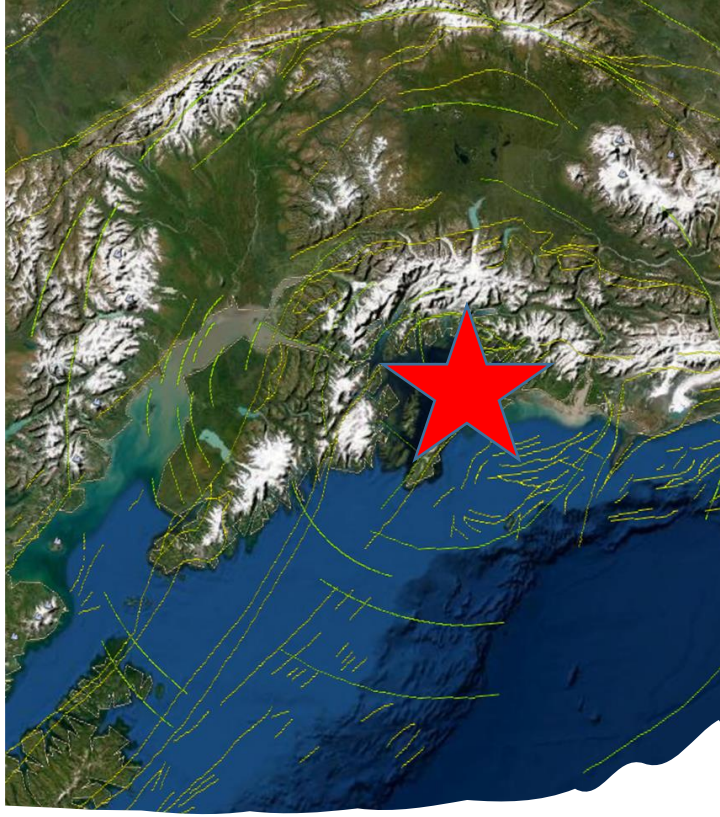
Mt. Dixon *Schliff-flache (*crenulated grooves and scratches on bedrock radiating from an impact).

Mt. Dixon Devonian limestone deposition post-dates central dome.

Microscopic spherules common at recumbent folds on either side of the central dome

Metamorphic breccia sampled.

No shatter cones, no PDF's.

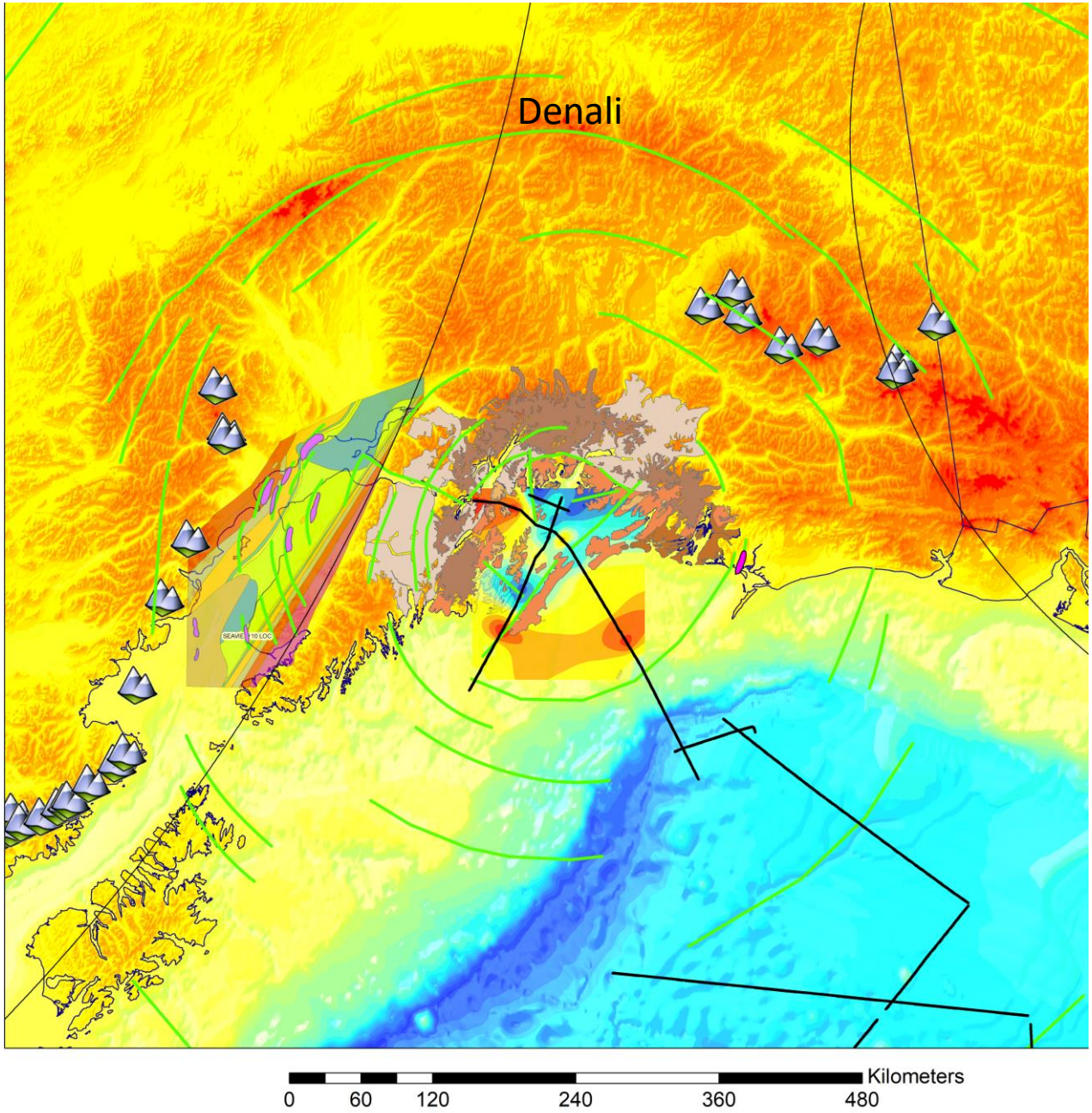


# Alaska Range and Prince William Sound

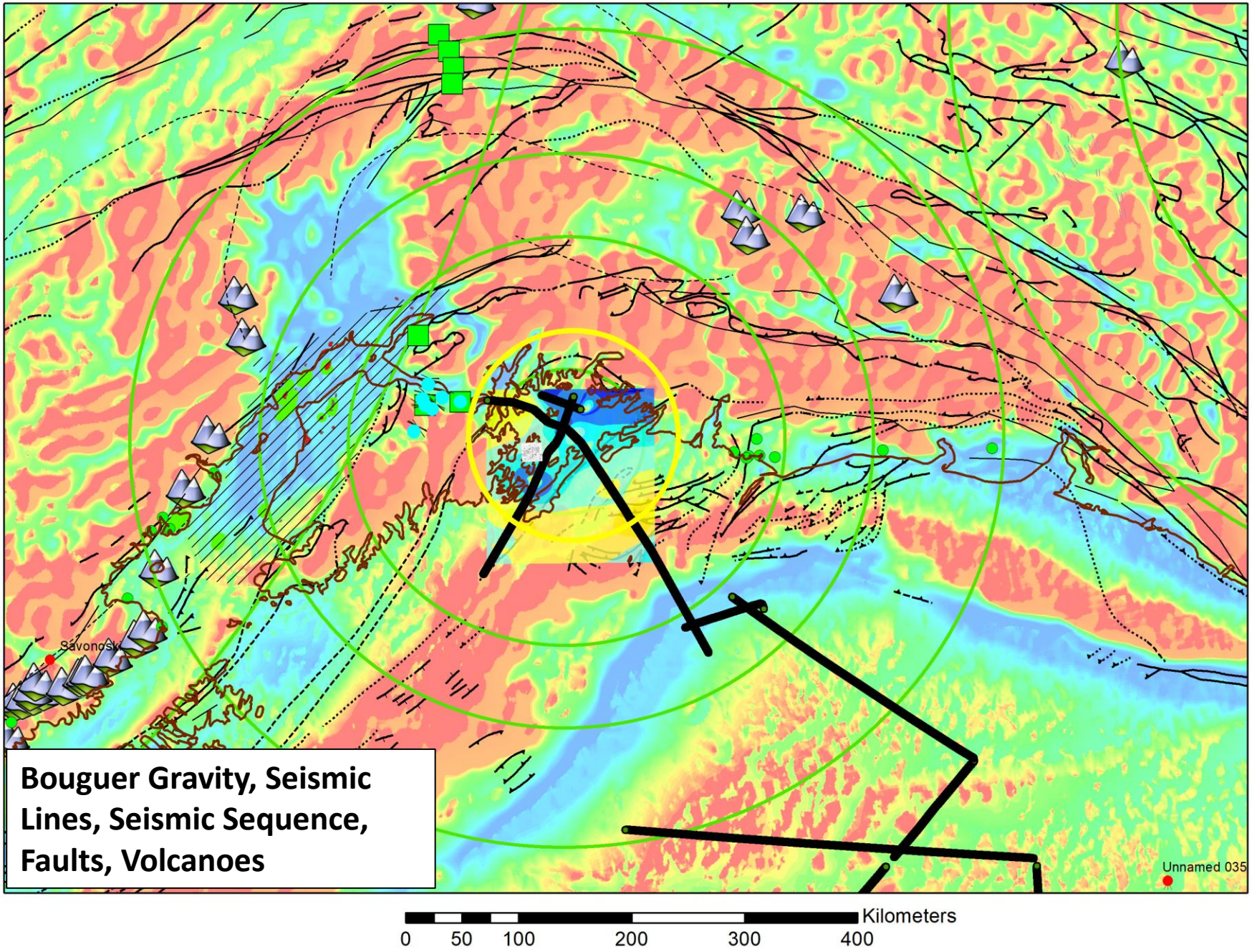
*Late Miocene 5.7 Ma*

Mt Dickey

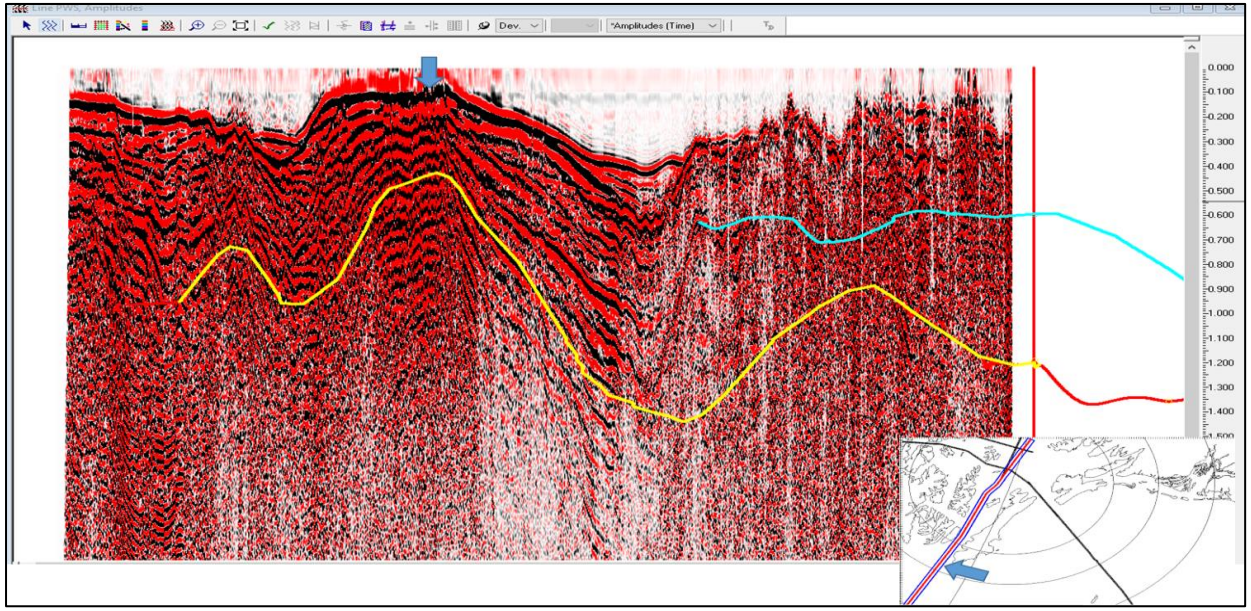
# Topography & Bathymetry: Alaska Range to PWS

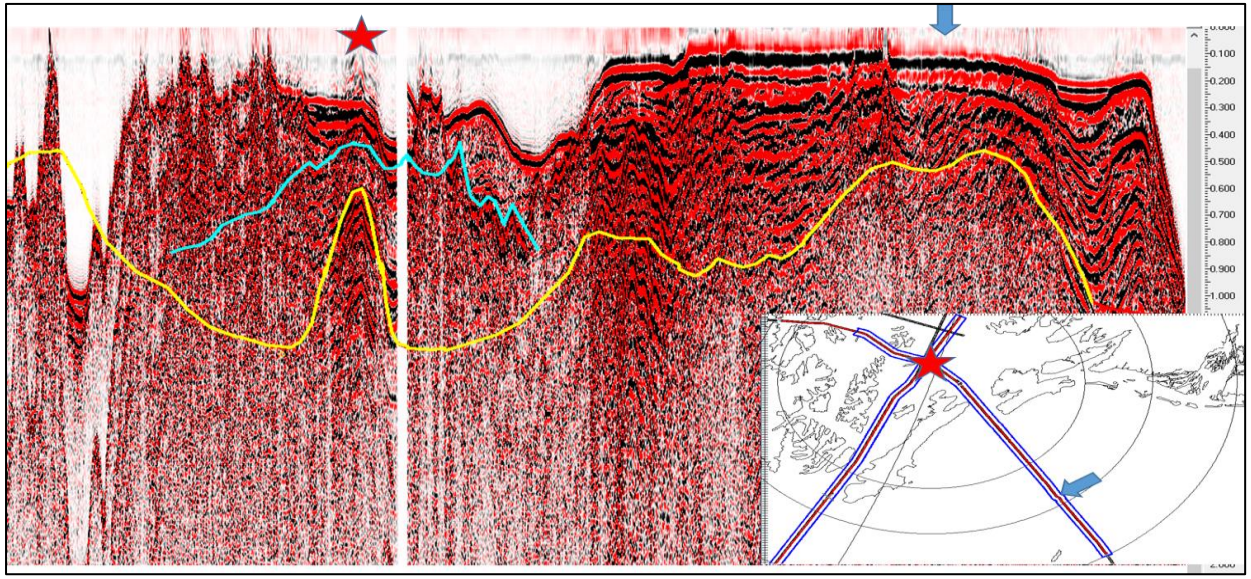


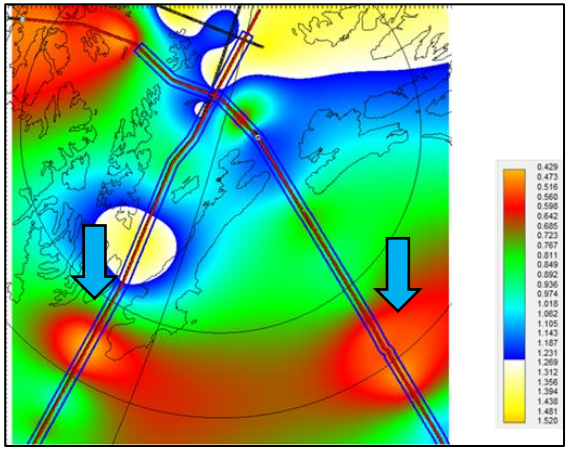

- Interrupted Volcano Chains
- Curvilinear surface geology
- Curvilinear mountain ranges
- Seismic Mapped
- Surface Lineations


Savonoski
Unnamed 035
Bouguer Gravity, Seismic Lines, Seismic Sequence, Faults, Volcanoes
Kilometers
0
50
100
200
300
400

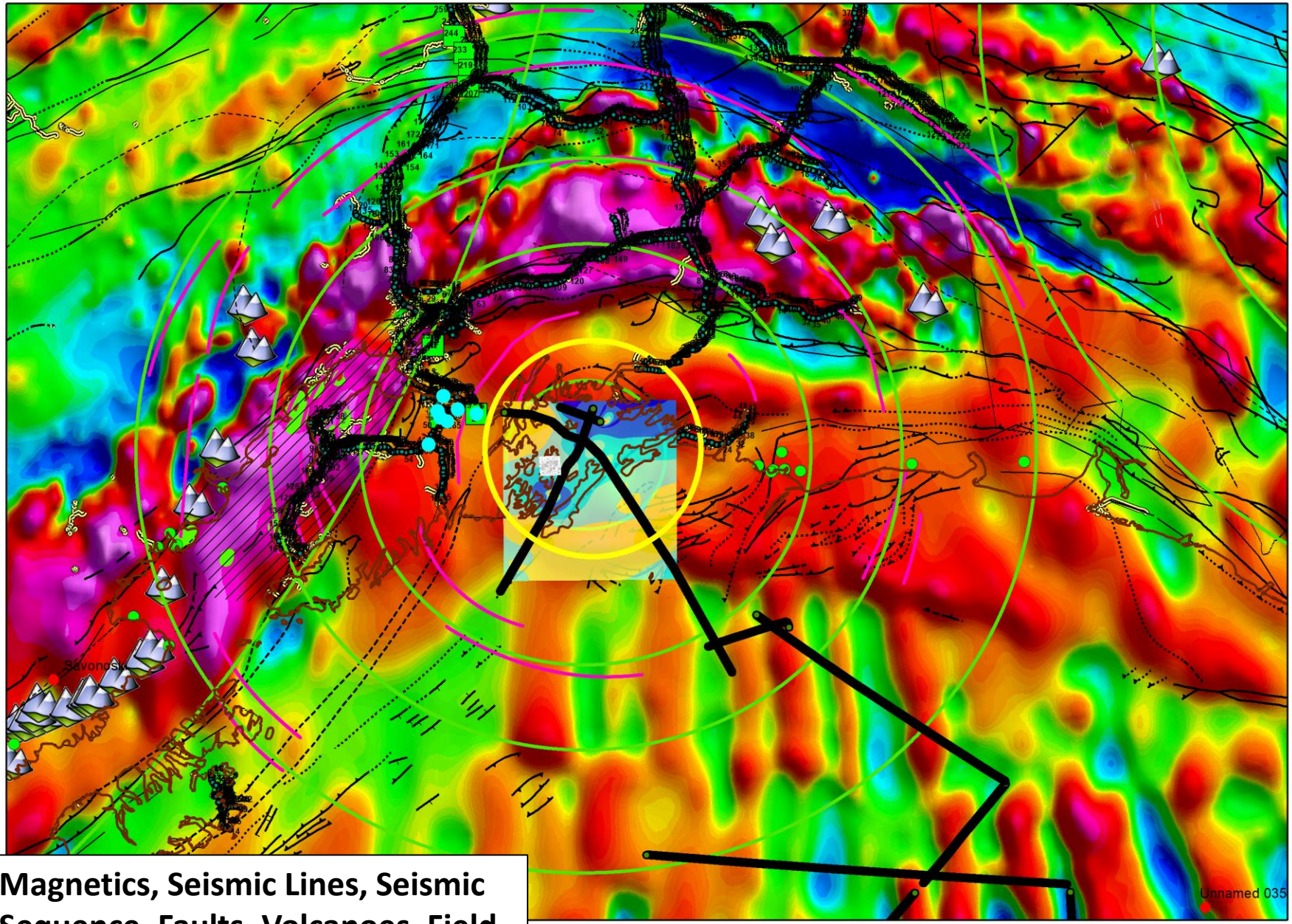
# Seismic: Encircling Arcuate Anticline and Center



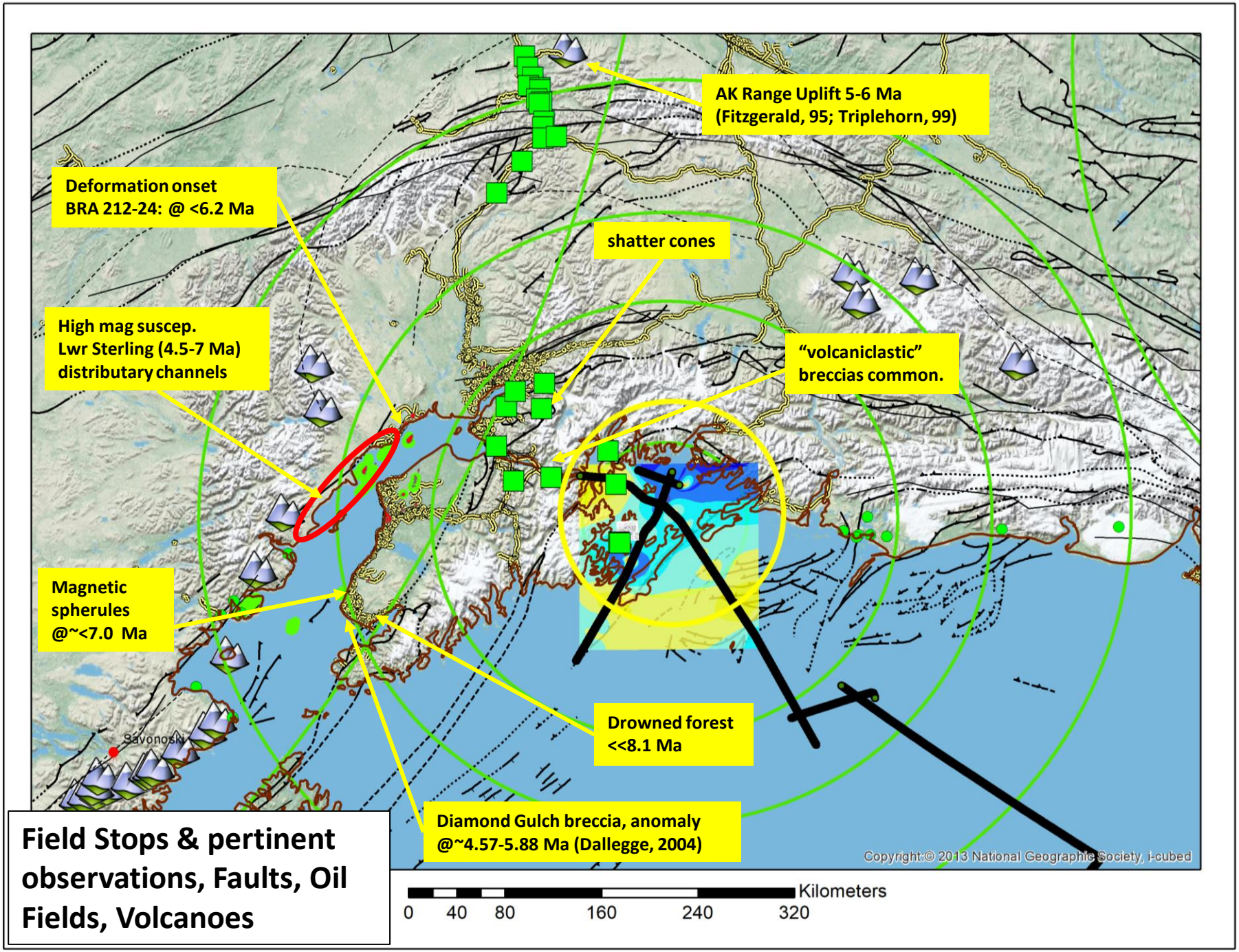




Yellow time horizon structure

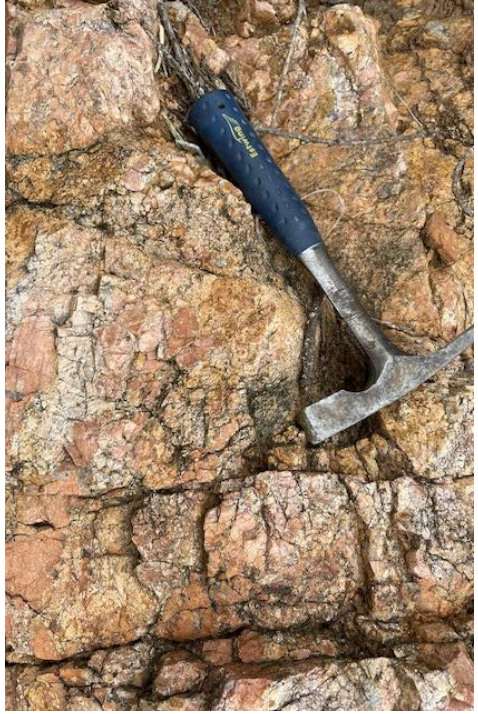



**Magnetics, Seismic Lines, Seismic Sequence, Faults, Volcanoes, Field Geology Stops**




**Field Stops & pertinent observations, Faults, Oil Fields, Volcanoes**

# Shattercones, Chugach Range, Eklutna, Alaska

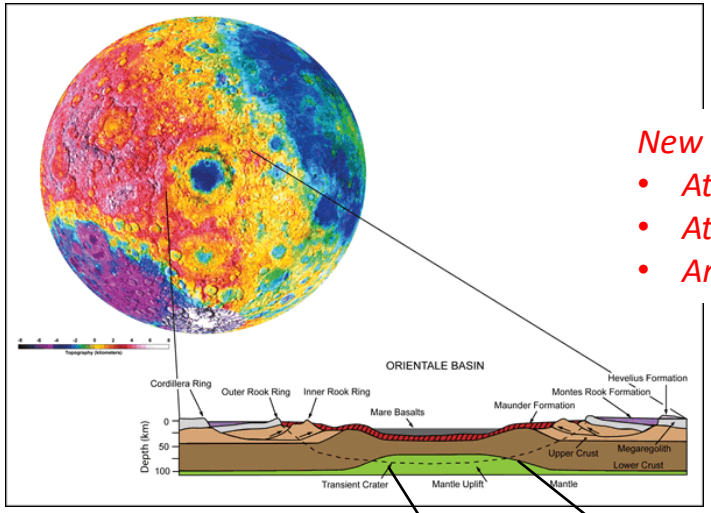


# Breccias Diagnostic

**Top Row Left to Right: Oligocene breccia, Bee Bluff crater, TX; metamorphic breccia Valley Springs Gneiss, 1.120 Ga, Llano Uplift, TX; breccia at Decaturville Crater, MO; Ordovician polymict breccia, Glover Bluff, WI**

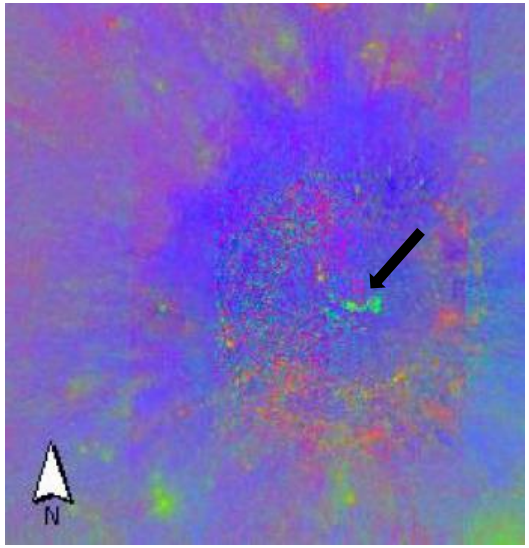
***Left: metamorphic breccia;*** **layered olivine,** ***clasts >3 G/CC,*** **Eklutna, AK.**

# Theories for Mantle Rock (>3.0 G/CC) at Surface



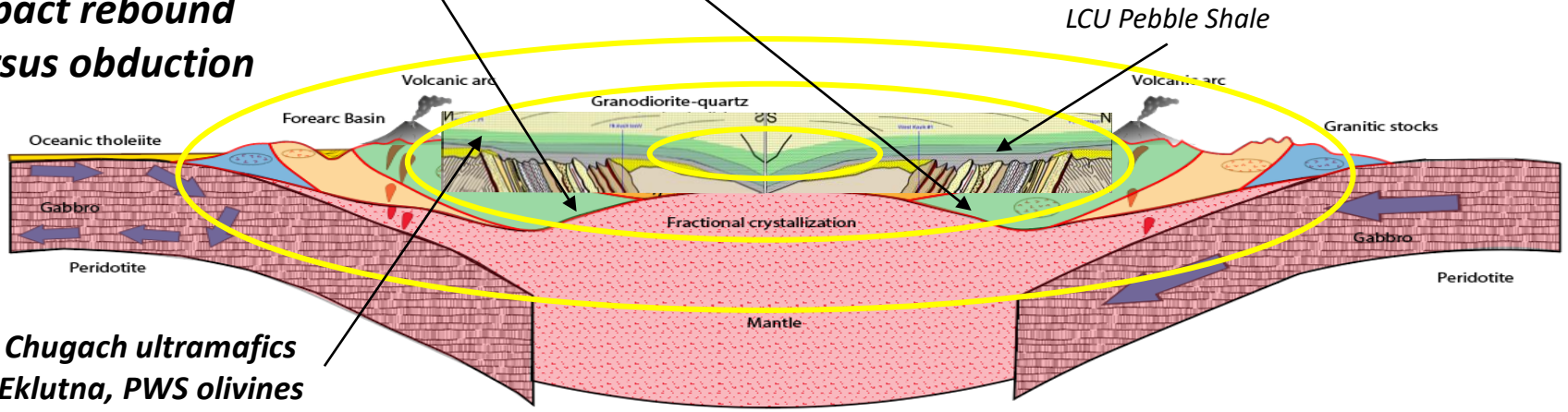

*New mafic crust:*

- *At mid-ocean ridges*
- *At dike swarms*
- *Ancient mare melt seas*



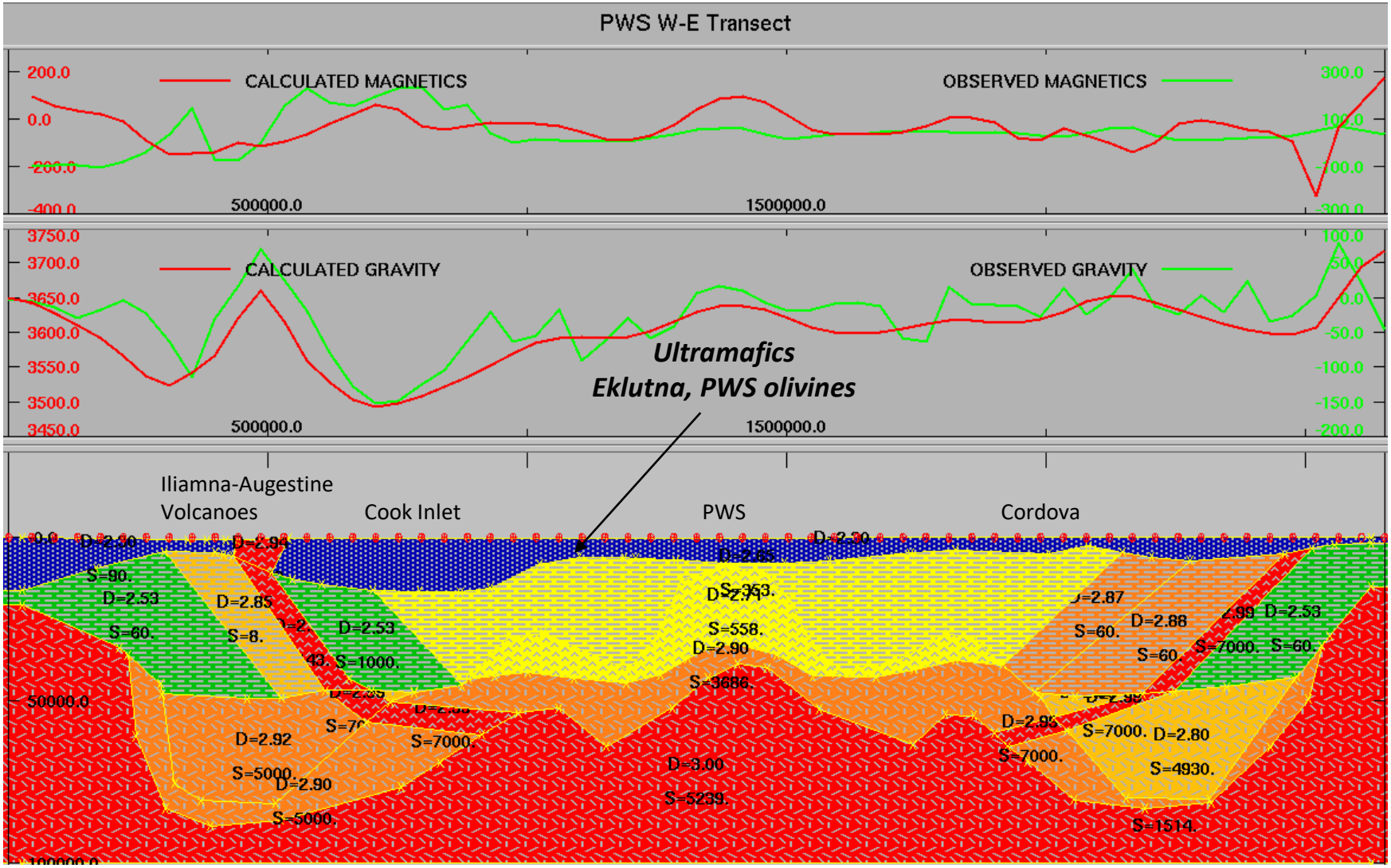

Uplifted mantle and mantle overturn, arrow indicates olivine troctolite in the central dome of this 93-km diameter crater, Clementine mission (Cohen, 2001).

***Olivine at the surface: Impact rebound versus obduction***




***Chugach ultramafics Eklutna, PWS olivines***

# Seismic-Gravity-Magnetics Model PWS W-E Transect



# PWS Diameter Predictions

## Crater

### Results for computing crater size from projectile diameter

Your Inputs:

**Projectile Descriptors**

Projectile Diameter 45000 meters
Projectile Density 3000 kg/m$^3$

~45 km dia bolide

**Impact Conditions**

Impact Velocity 50 km/sec
Impact Angle 35 degrees

**Target Descriptors**

Target Density 1500 kg/m$^3$
Acceleration of Gravity 9.8 m/sec$^2$
Target Type loose sand

### Results

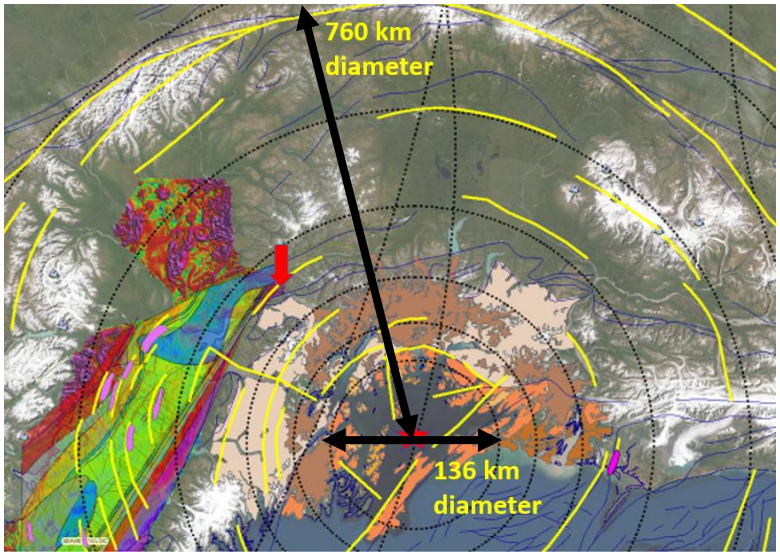
The three scaling laws yield the following *transient* crater diameters (note that diameters are measured at the pre-impact surface. Rim-to-rim diameters are about 1.25 times larger!)

| | |
|---|---|
| Yield Scaling | 6.62 x 10$^5$ meters |
| Pi Scaling (Preferred method!) | 2.25 x 10$^5$ meters |
| Gault Scaling | 3.68 x 10$^5$ meters |
| Crater Formation Time | 1.05 x 10$^2$ seconds |

Using the Pi-scaled transient crater, the *final* crater is a Peak-ring crater with a rim-to-rim diameter of 7.41 x 10$^5$ meters.

This impactor would strike the target with an energy of 1.79 x 10$^{26}$ Joules (4.27 x 10$^{10}$ MegaTons).

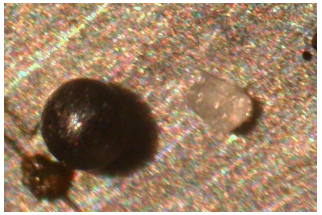


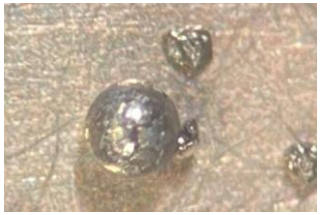



380 km radius from center to Denali Mountain.

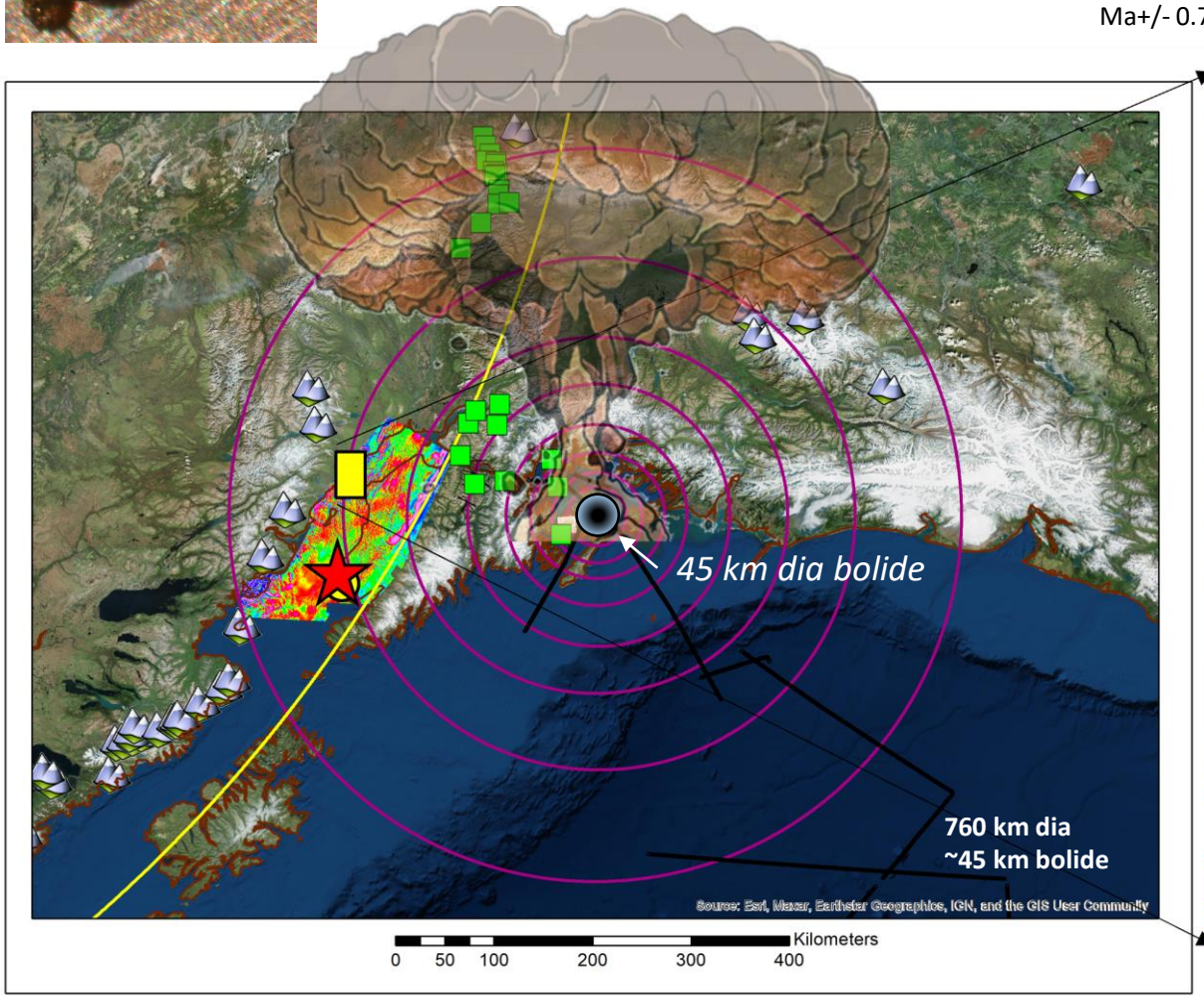
*741 km diameter calculated, compared to measured 760 km diameter.*

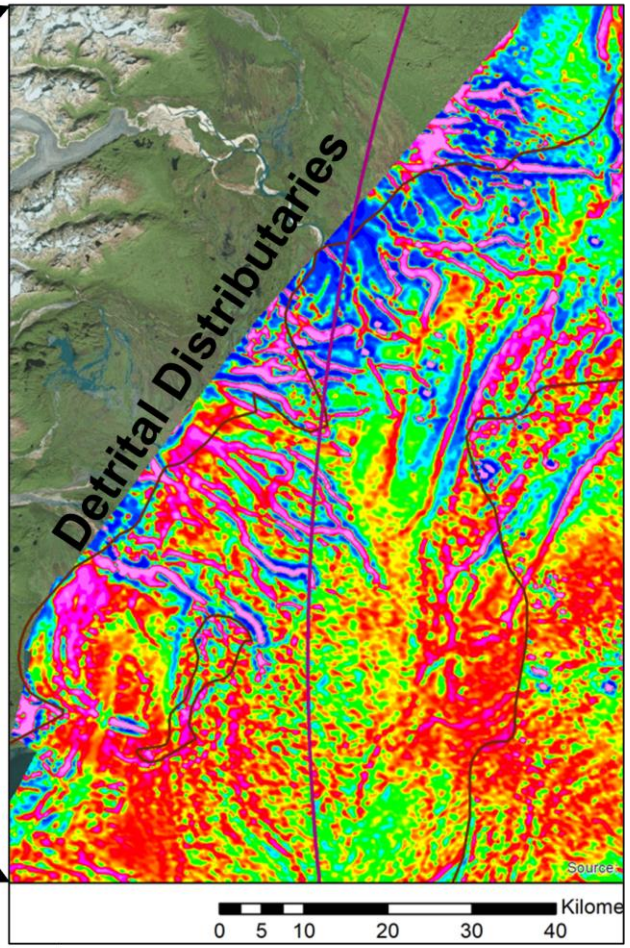
# Metallic Spherules 5.7 Ma Hypothesis



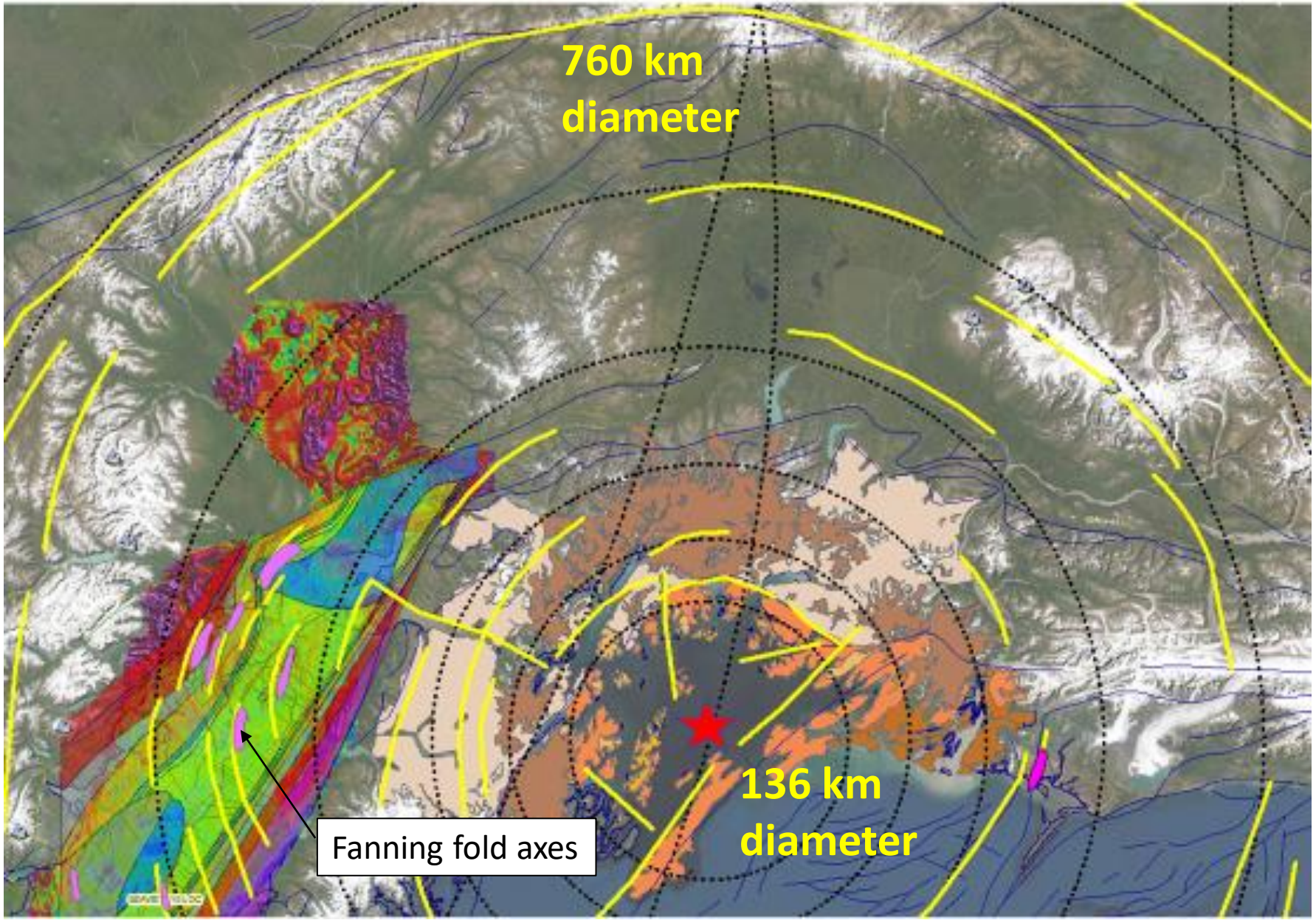


Ar40/Ar39 age dates: 4.57-5.88
Ma+/- 0.72 (Dallegge, 2004)

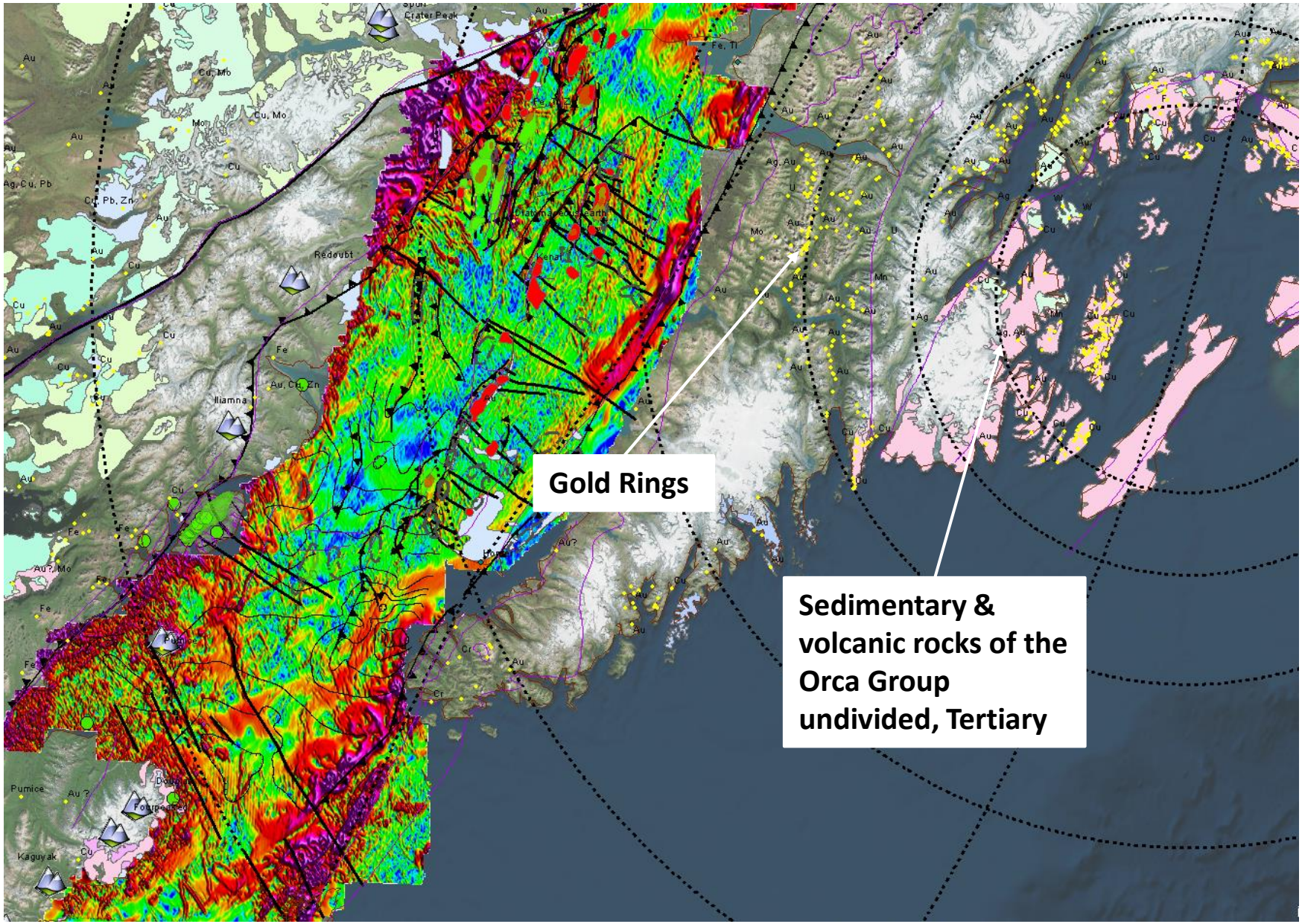


# Commercial Impact: Hydrocarbon Fields



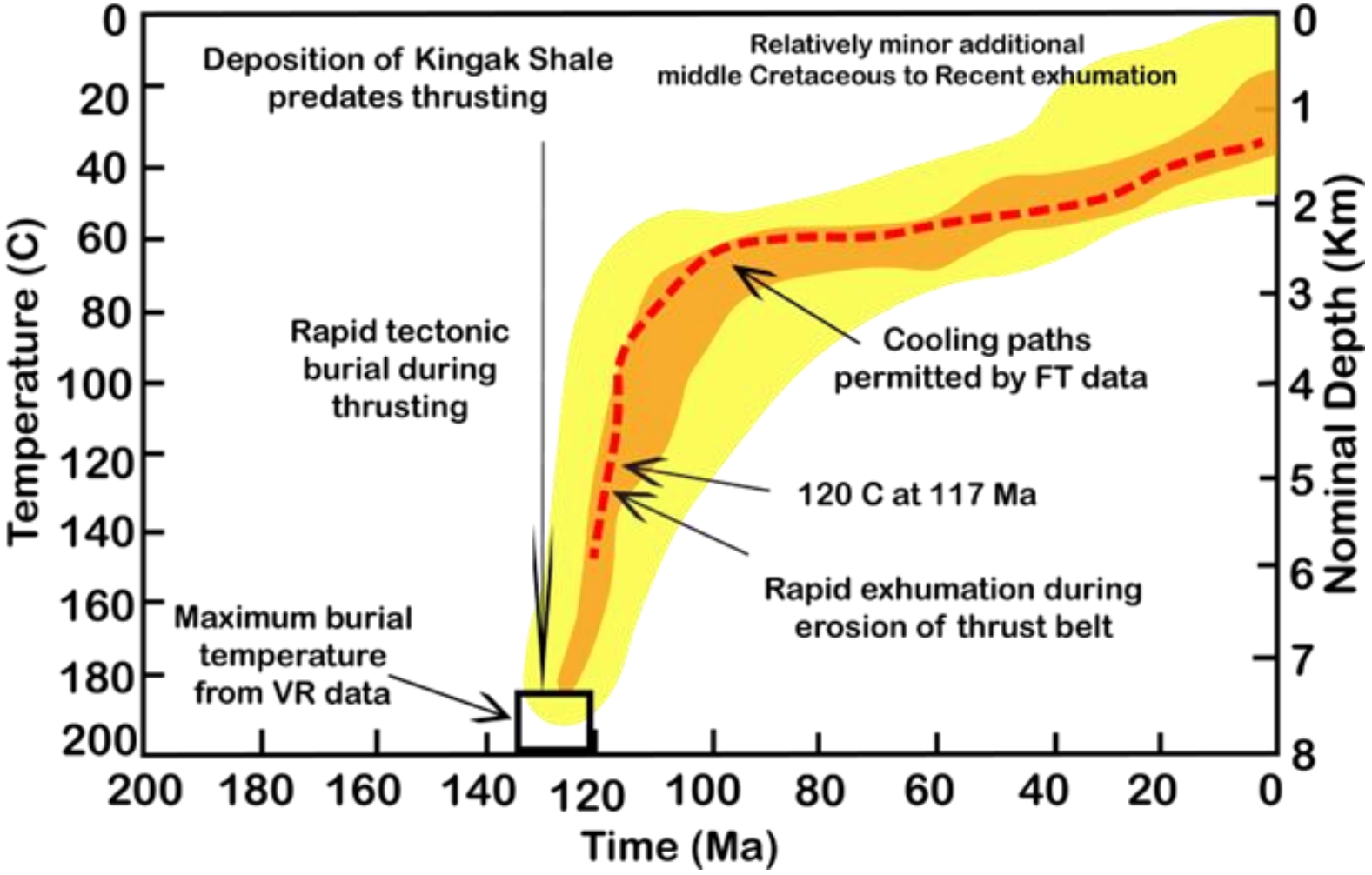
# Prediction of Gold Deposits on Rings




*Lower Cretaceous, ~120 Ma*

# Brooks Range, North Slope

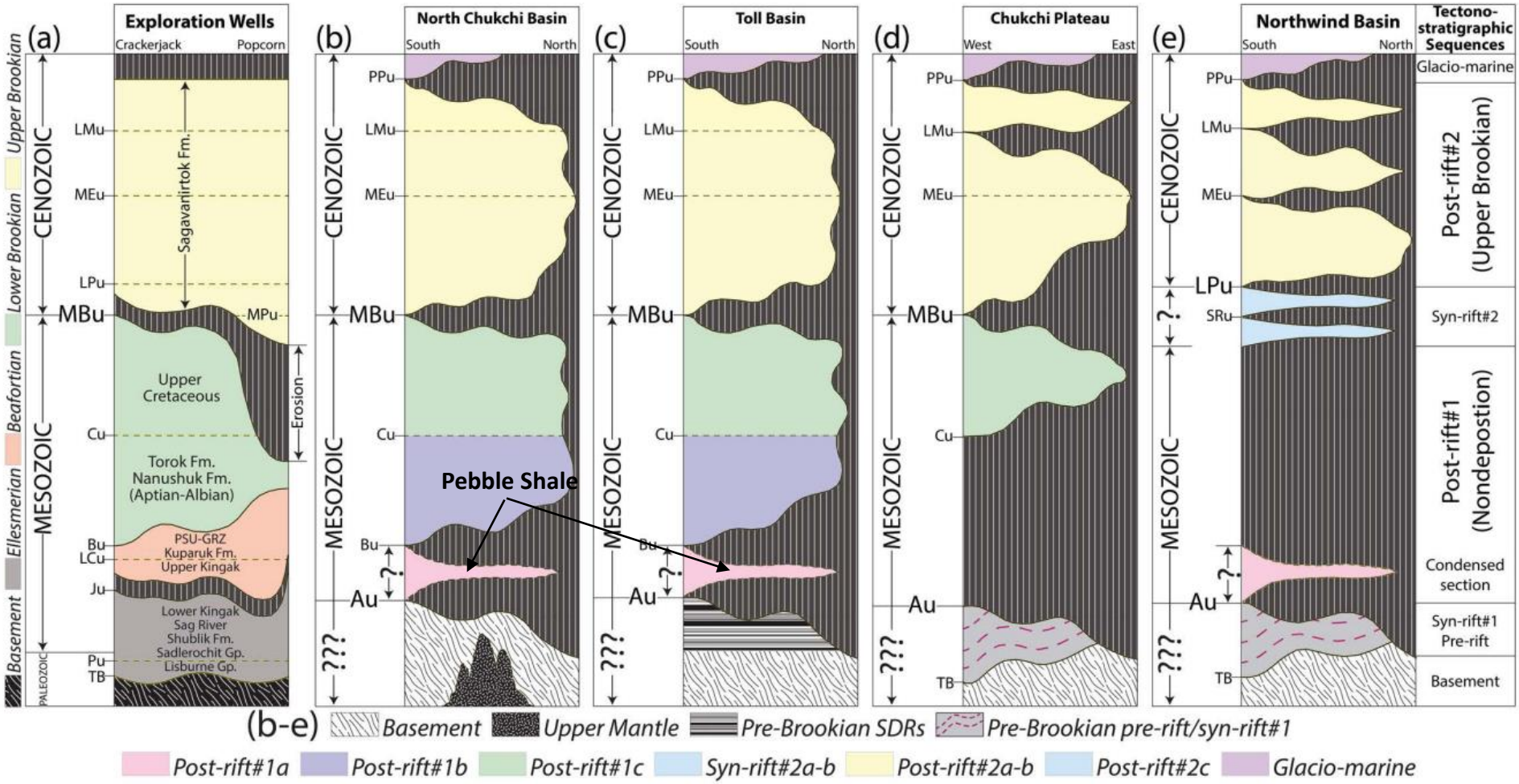
# Thermal History of the North Arctic




Onset of rapid burial and thrusting during Lower Cretaceous ~ 120 Ma.

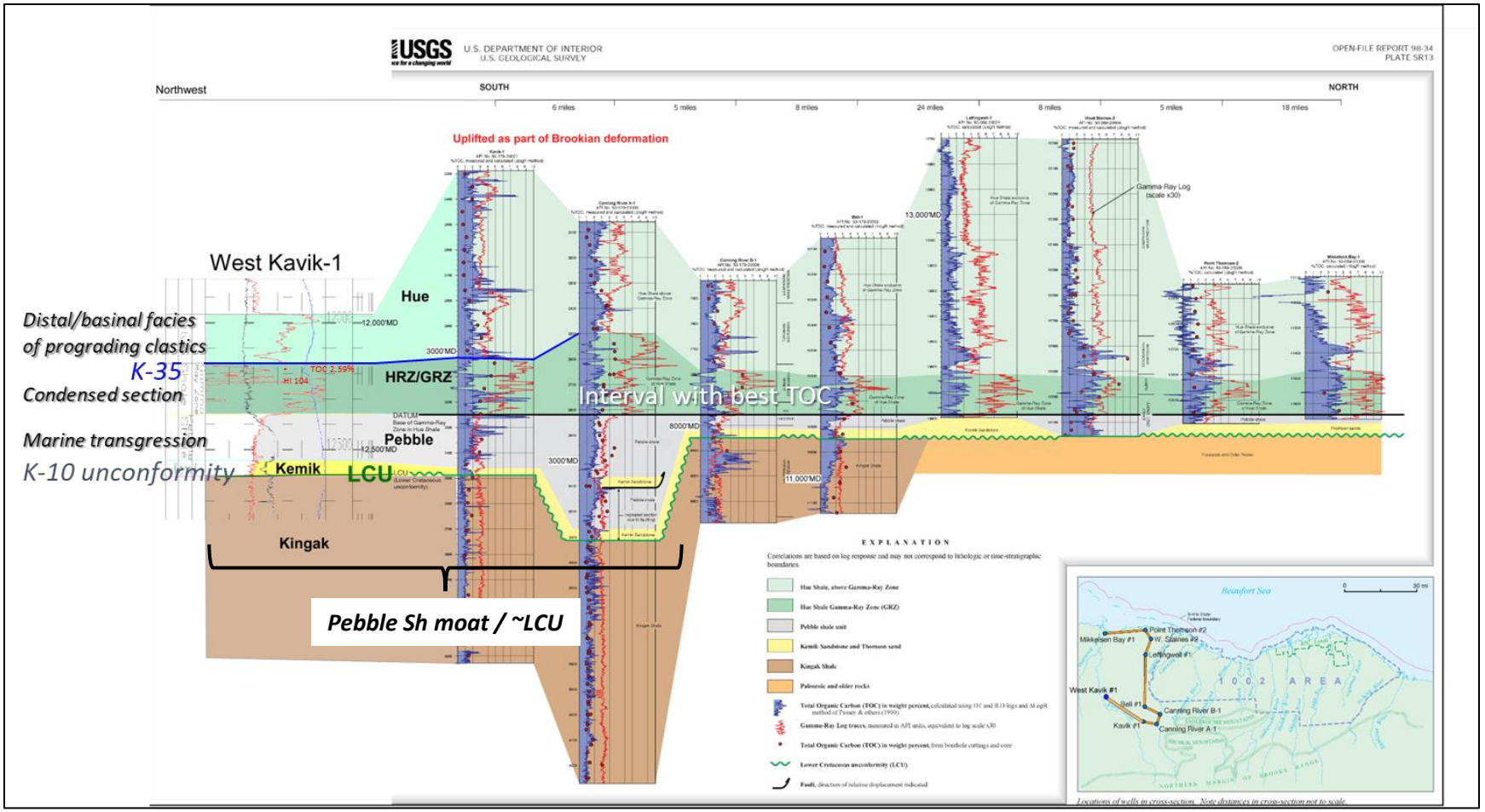
# Canadian Arctic: Innuition Orogeny, From Embry, 1991

Rapid burial / thrusting onset ~ 120 Ma
Pebble Shale ~99.6-136.4 Ma (USGS)



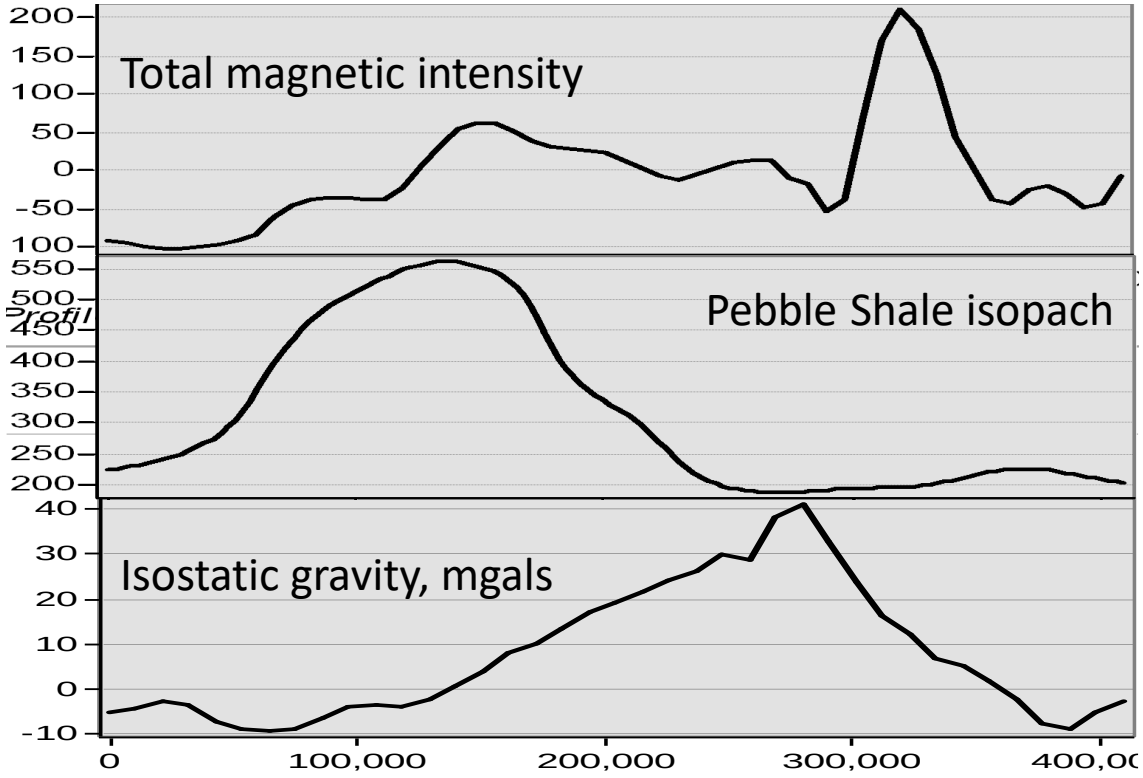

*From Ilhan & Coakley, 2018*

# Pebble Shale Stratigraphic Cross Section



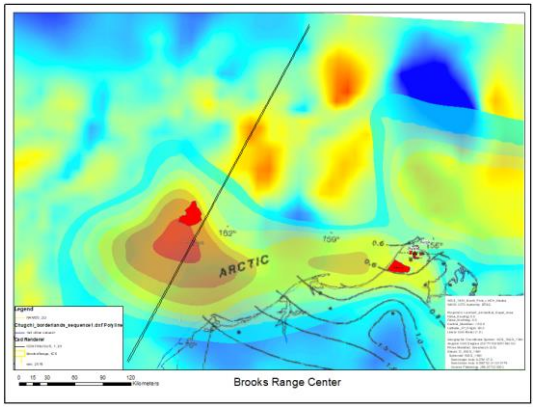

Fish Creek slide lies atop the Pebble Shale, and the Pebble Shale lies atop the Lower Cretaceous Unconformity

# Relationship of Pebble Shale Thickness and Potential Fields Data



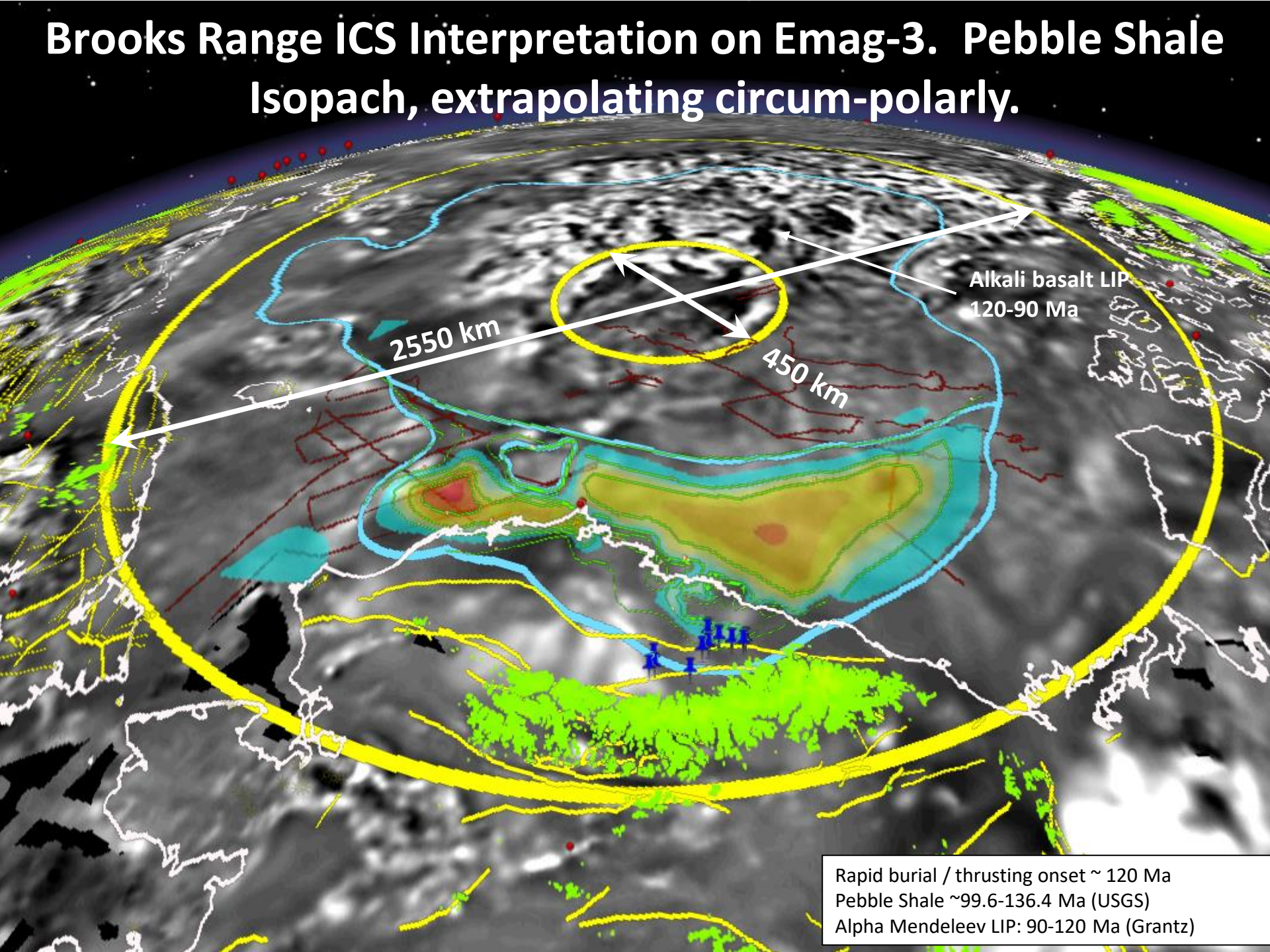

Where we have subsurface control, the gravity highs have thin Pebble Shale, and that the gravity lows have thick Pebble Shale.

In our area of good control for wells, seismic, and potential fields data, thick Lower Cretaceous Pebble Shale correlates with gravity minima, and vice versa. Given this observation, the correlation is extended across the arctic regions.



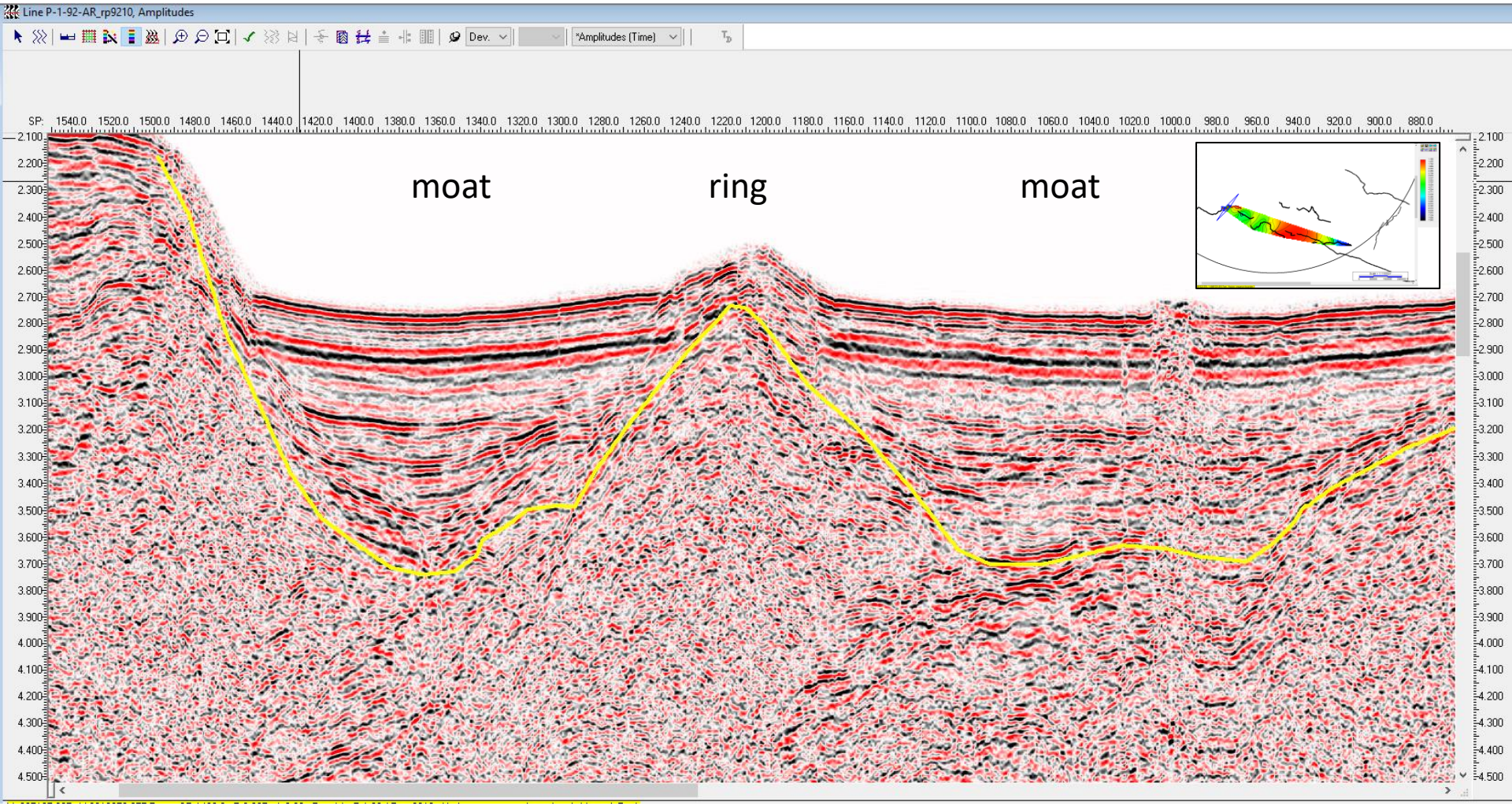

*Modified from Exploration Geosciences, 1999.*

# Brooks Range ICS Interpretation on Emag-3. Pebble Shale Isopach, extrapolating circum-polarly.

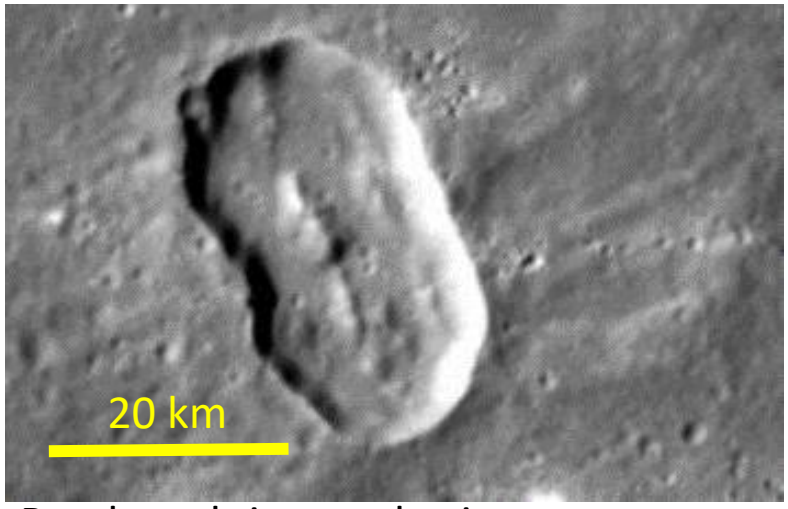



Rapid burial / thrusting onset ~ 120 Ma
Pebble Shale ~99.6-136.4 Ma (USGS)
Alpha Mendeleev LIP: 90-120 Ma (Grantz)

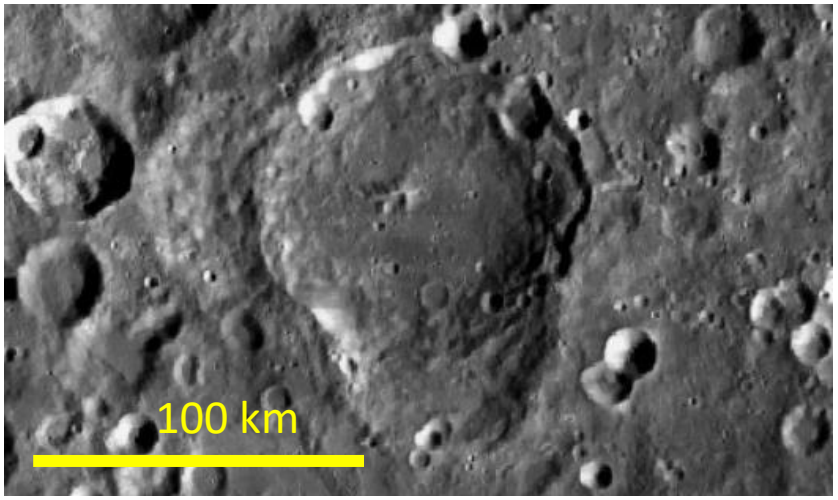
# Chukchi Borderlands / Northwind Basin 2D Seismic



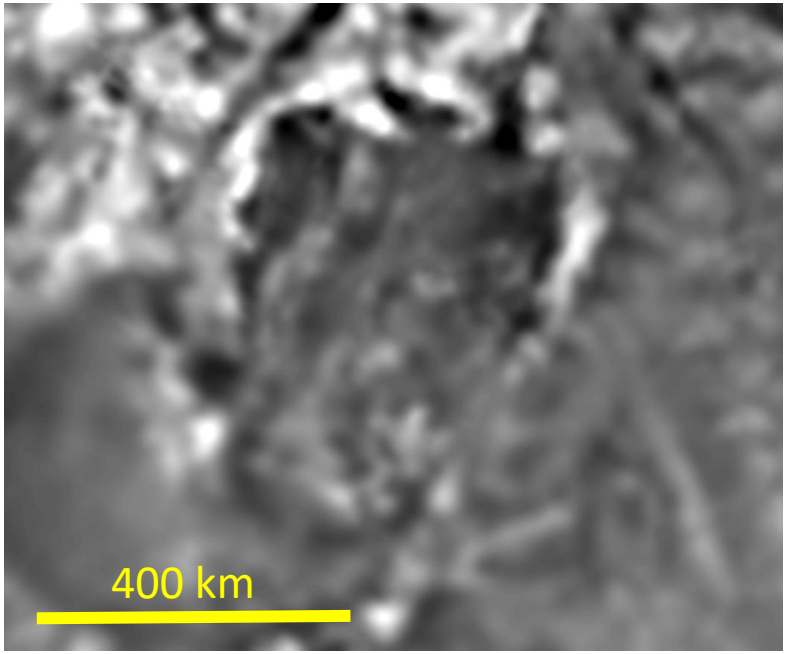
# Center Wormhole Geometries



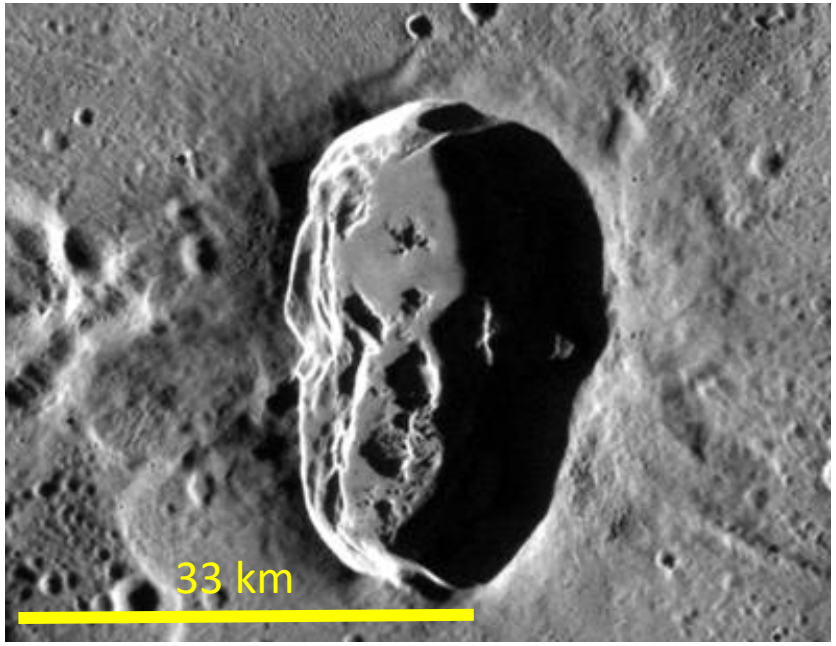

Rembrandt impact basin




Joule crater, farside of Moon

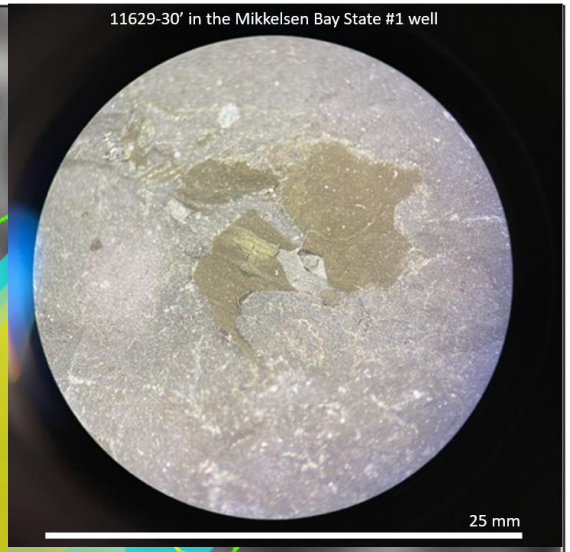



Chukchi Borderland Emag




Hovnatanian crater, Mercury.

# Field Observations: Pebble Shale




ARCTIC OCEAN

Awak Awak

Mikkelsen Bay State #1

Outcrop

NPRA

ANWR

Legend
PebbleShaleZeroLine ICS
NAMSS 2D
Chugchi_borderlands_sequence1.dxf Polyline
<all other values>
Cad Renderer
CONTINUOUS, 7, 25
BrooksRange ICS
wsv 2016

WGS_1984_North_Pole_LAEA_Alaska
WKID: 3572 Authority: EPSG

Projection: Lambert_Azimuthal_Equal_Area
False_Easting: 0.0
False_Northing: 0.0
Central_Meridian: -150.0
Latitude_Of_Origin: 90.0
Linear Unit Meter (1.0)

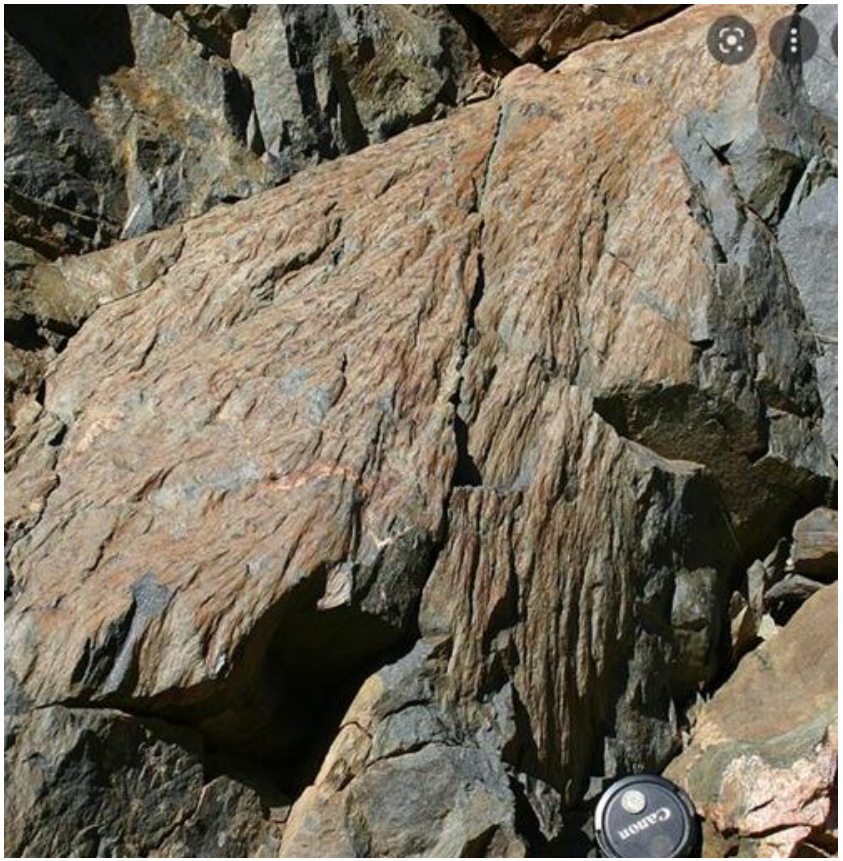
Geographic Coordinate System: GCS_WGS_1984
Angular Unit Degree (0.0174 532 925 199 433)
Prime Meridian: Greenwich (0.0)
Datum: D_WGS_1984
Spheroid: WGS_1984
Semimajor Axis: 6.3781 37.0
Semiminor Axis: 6.3567 52.31 424 5179
Inverse Flattening: 298.25 722 356.3

0 40 80 160 240 320
Kilometers

Brooks Range Center

# Possible Shatter Cones@ Brooks Range

North Slope, Early Cretaceous
“Nanushuk” Group



Analogue: Mistastin Lake
crater shattercones.

- Rapid burial / thrusting onset ~ 120 Ma
- Pebble Shale ~99.6-136.4 Ma (USGS)
- Alpha Mendeleev LIP: 90-120 Ma (Grantz)
- Nanushuk SC (?): Early Cretaceous

# Chukchi Borderlands Diameter Predictions

## Crater

### Results for computing crater size from projectile diameter

Your Inputs:

**Projectile Descriptors**

Projectile Diameter 70000 meters
Projectile Density 3000 $kg/m^3$

~70 km dia bolide

**Impact Conditions**

Impact Velocity 50 km/sec
Impact Angle 45 degrees

**Target Descriptors**

Target Density 1500 $kg/m^3$
Acceleration of Gravity 9.8 $m/sec^2$
Target Type liquid water

### Results

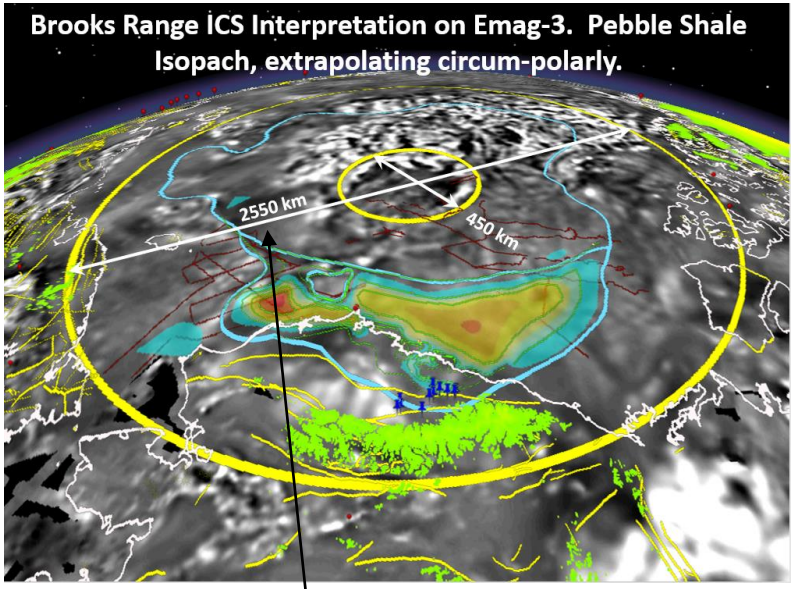
The three scaling laws yield the following *transient* crater diameters (note that diameters are measured at the pre-impact surface. Rim-to-rim diameters are about 1.25 times larger!)

| | |
|---|---|
| Yield Scaling | $1.05 \times 10^6$ meters |
| Pi Scaling (Preferred method!) | $6.51 \times 10^5$ meters |
| Gault Scaling | $5.73 \times 10^5$ meters |
| Crater Formation Time | $2.03 \times 10^2$ seconds |

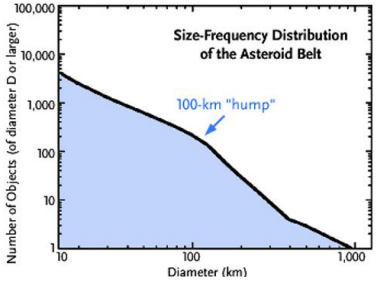
Using the Pi-scaled transient crater, the *final* crater is a Peak-ring crater with a rim-to-rim diameter of $0.26 \times 10^7$ meters.

This impactor would strike the target with an energy of $6.73 \times 10^{26}$ Joules ($1.61 \times 10^{11}$ MegaTons).

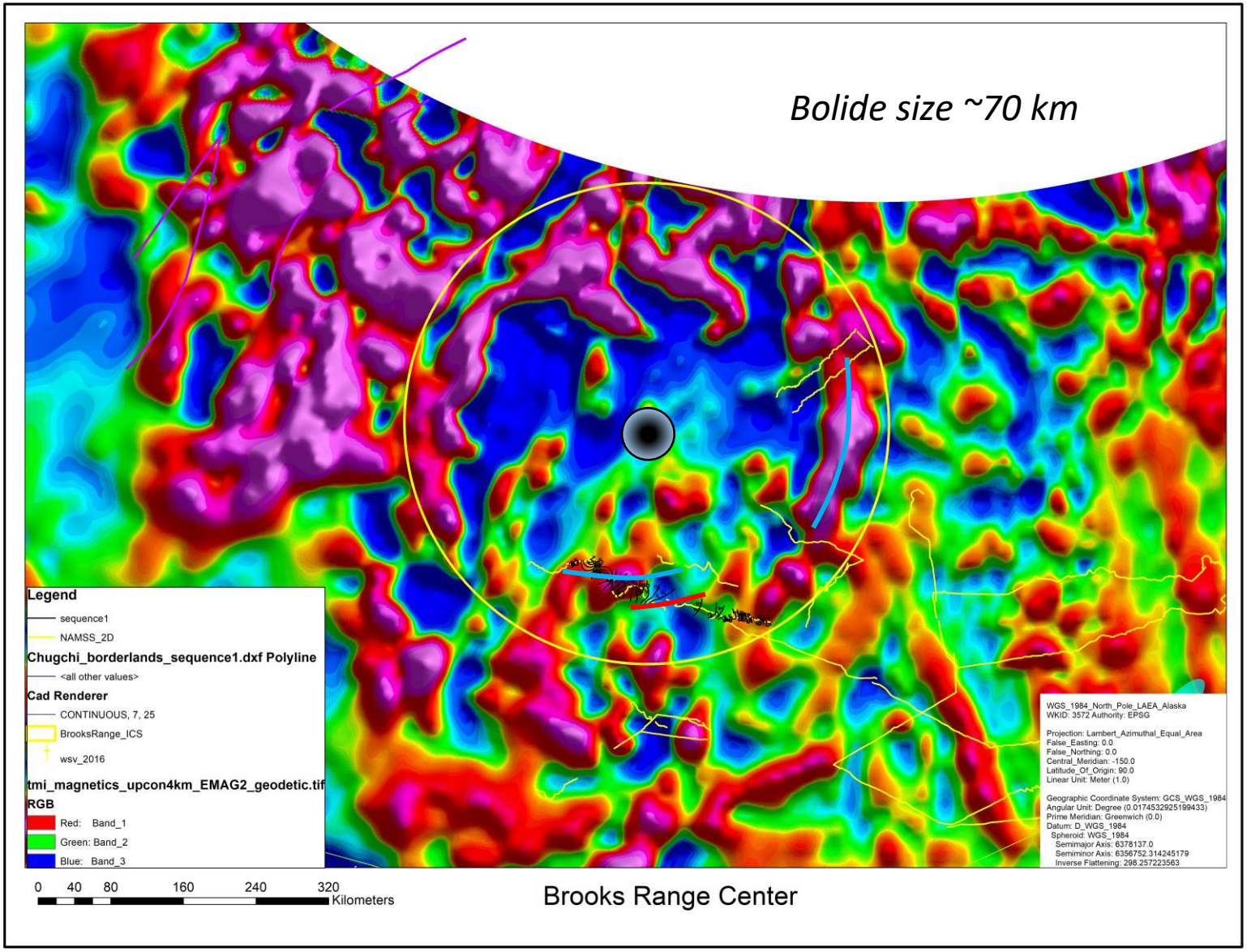




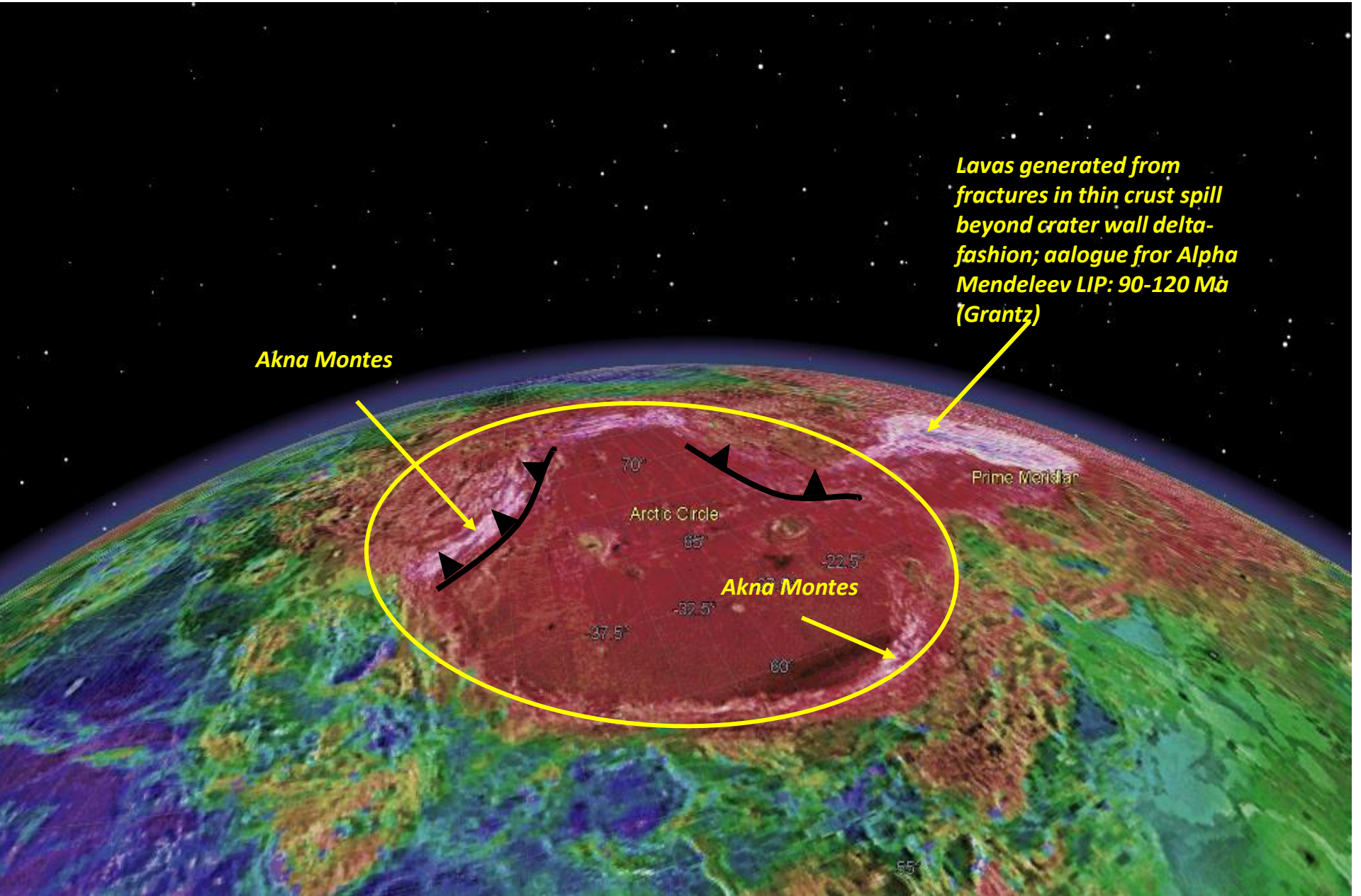

Chukchi Borderland, Emag-2
Rim to rim: 2550 km measured;
2600 km predicted.

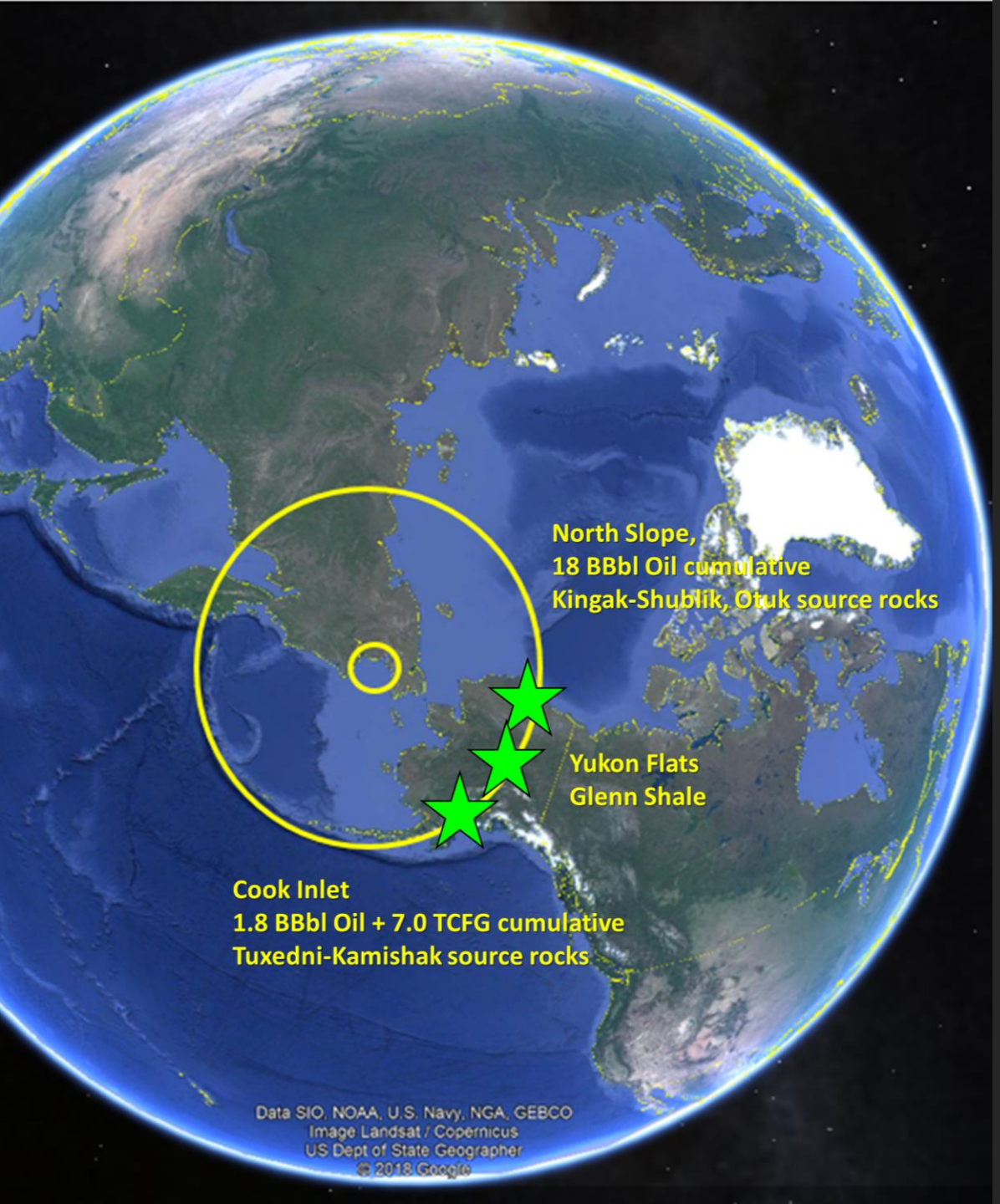


# Center Magnetics “Wormhole”



# Akna Montes, Arcuate Range, 2000 km Diameter





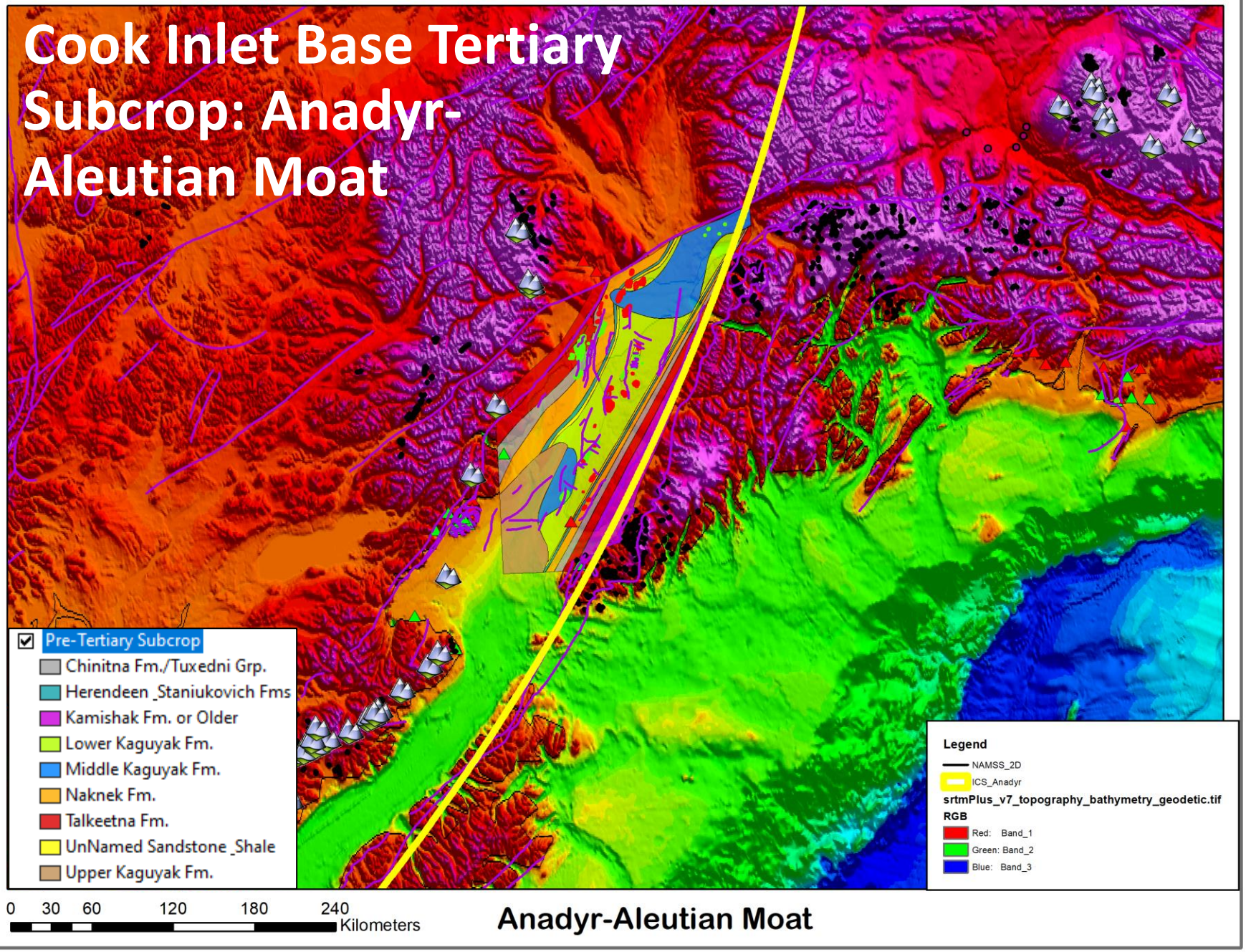

*The most speculative, yet largest economic potential for oil and gas*

*Upper Triassic*

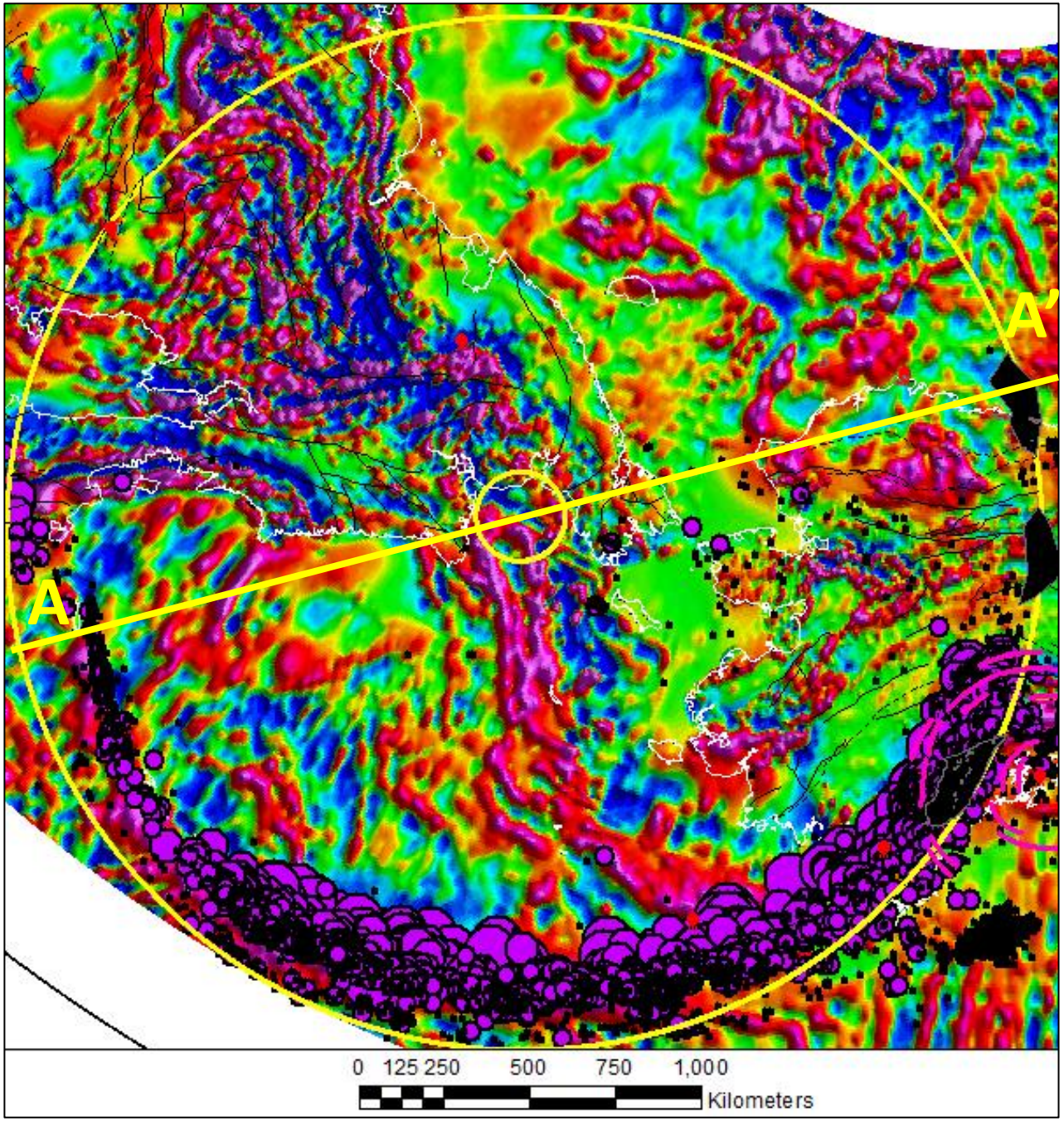
# ANADYR-ALEUTIAN & REGIONAL INTEGRATION

Aleutian Crater, Earth:
3190 km diameter

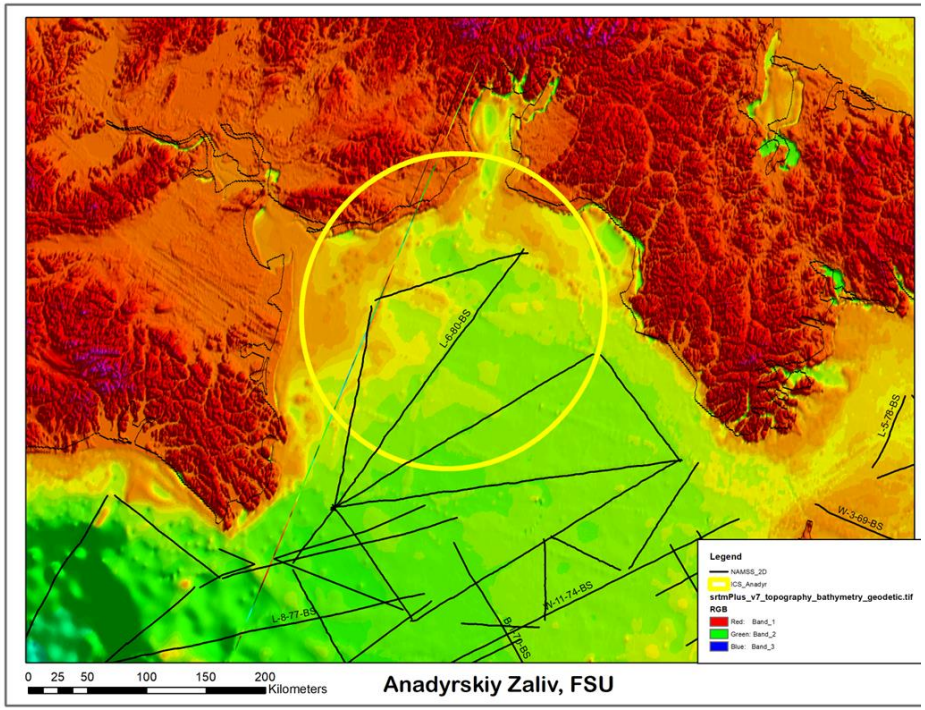
# Cook Inlet Base Tertiary Subcrop: Anadyr-Aleutian Moat



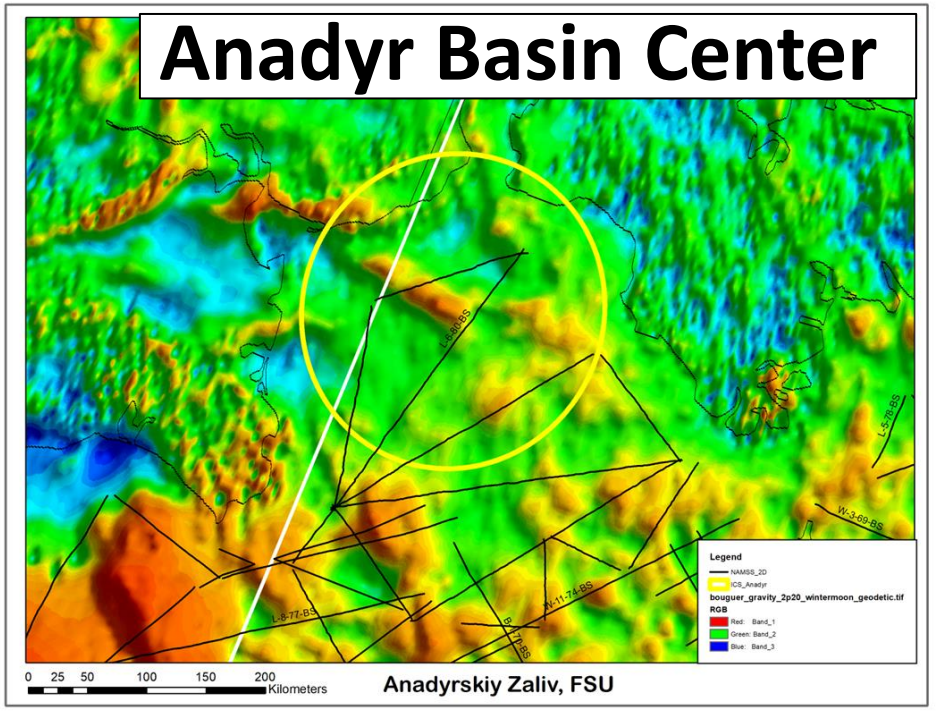
# Anadyr-Aleutian Magnetics & Earthquake Epicenters

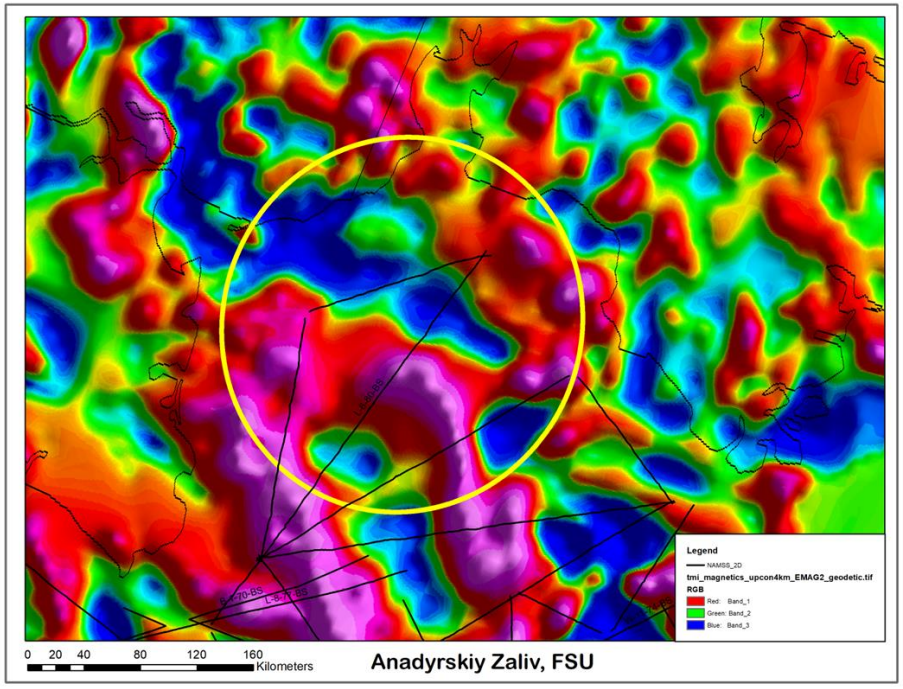



Anadyr-Aleutian Chain, Alaska, Bering Sea, to East Siberia. Emag2 colorfill contours, multi-ringed crater analyses, and bubble symbols representing earthquake epicenters. The deeper the earthquakes, the larger the bubble. The earthquakes show a bowl-shaped depression deepening toward the center of the basin, at Anadyr. Note characteristic wheel and spoke symmetry.

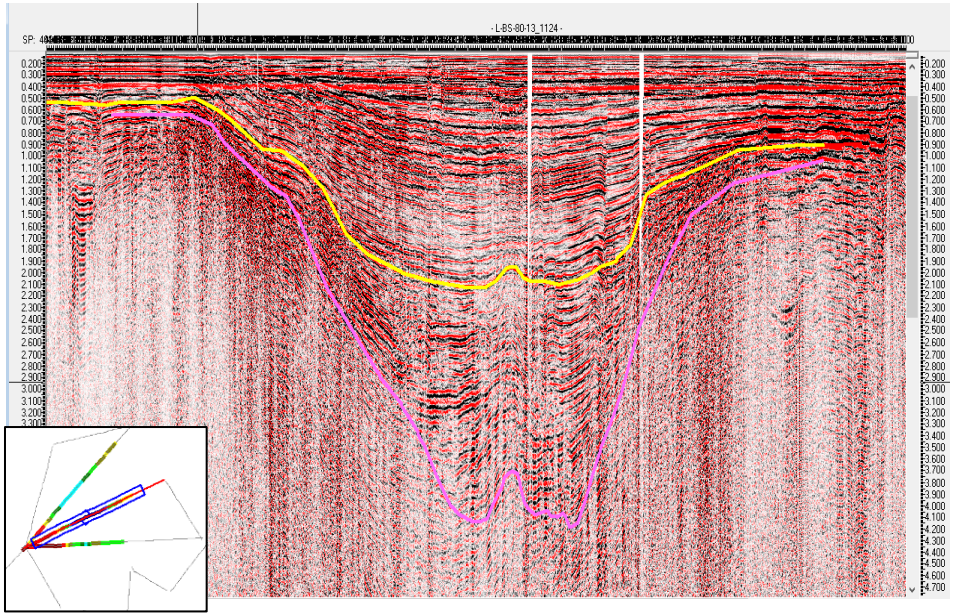



# Anadyr Basin Center

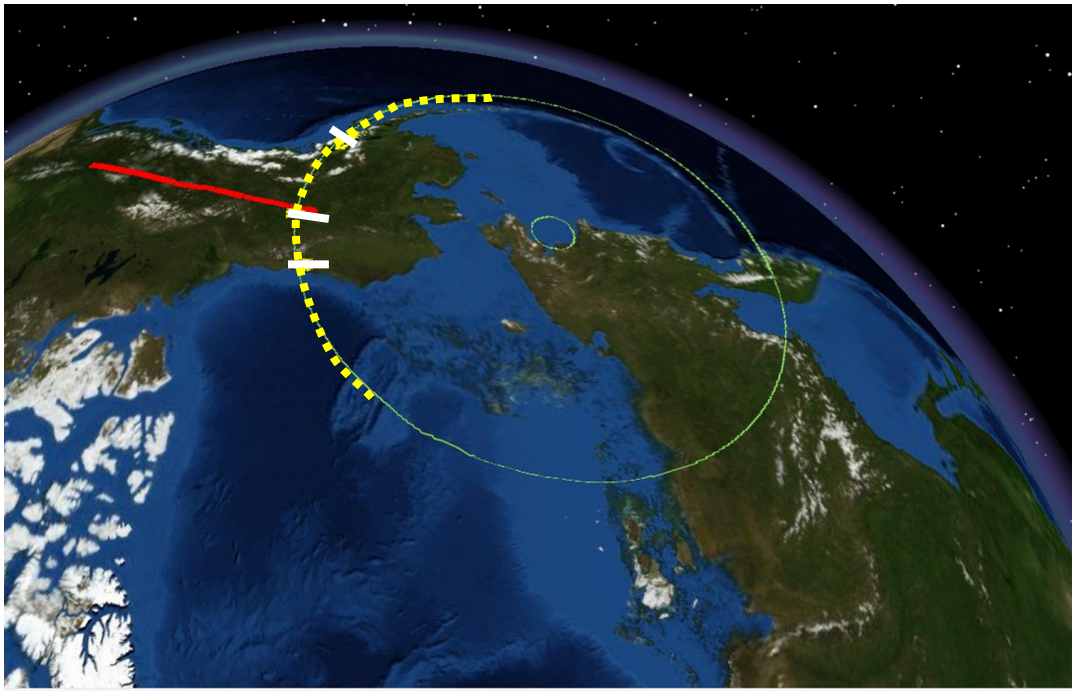


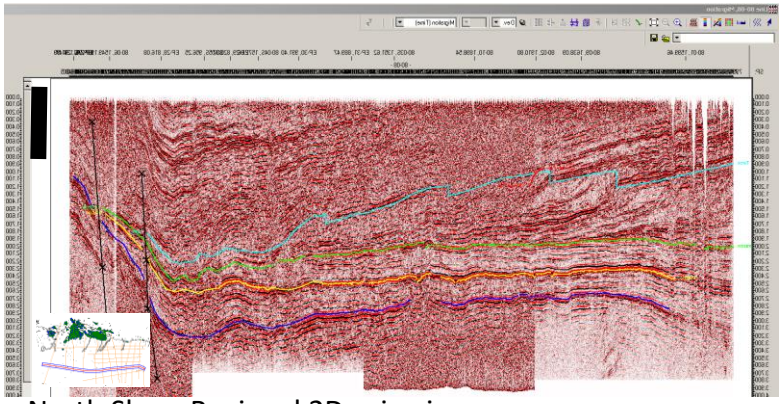

## Anadyr 2D Seismic Data, Southwest to Northeast Profile



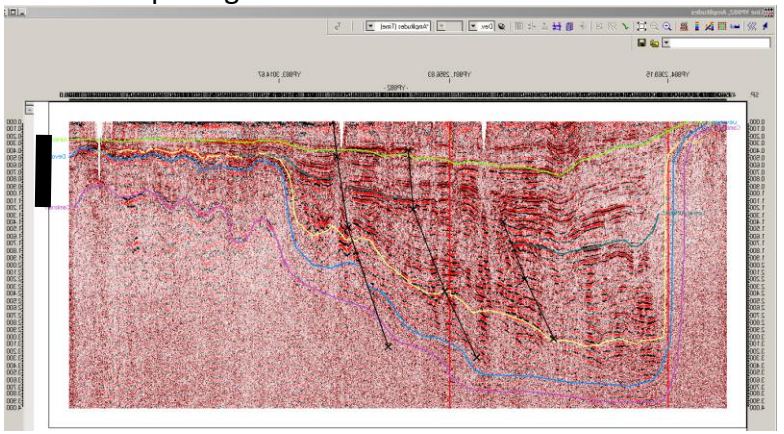
# Anadyr-Aleutian Structure 2D Seismic



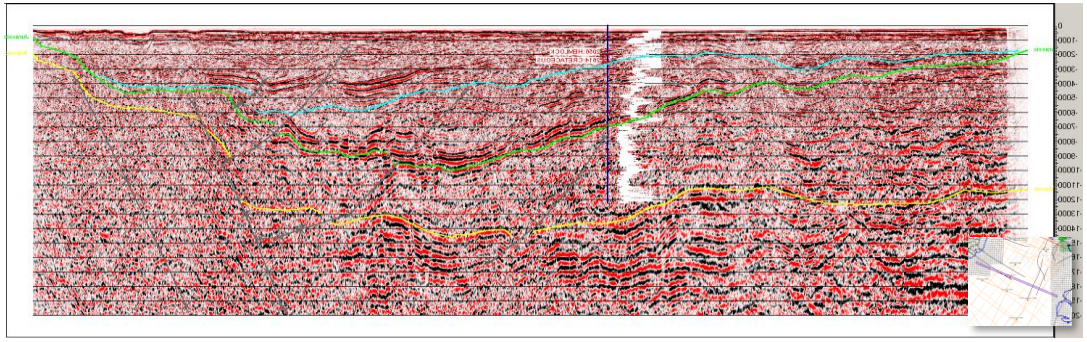
Global perspective view towards the south of the Anadyr-Aleutian multi-ringed basin.



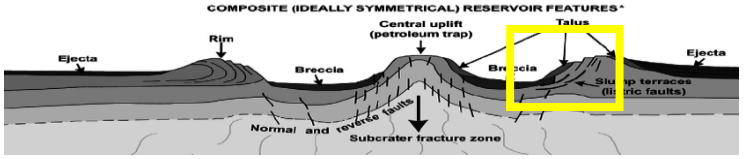
North Slope Regional 2D seismic.



Yukon Flats Basin 2D seismic.



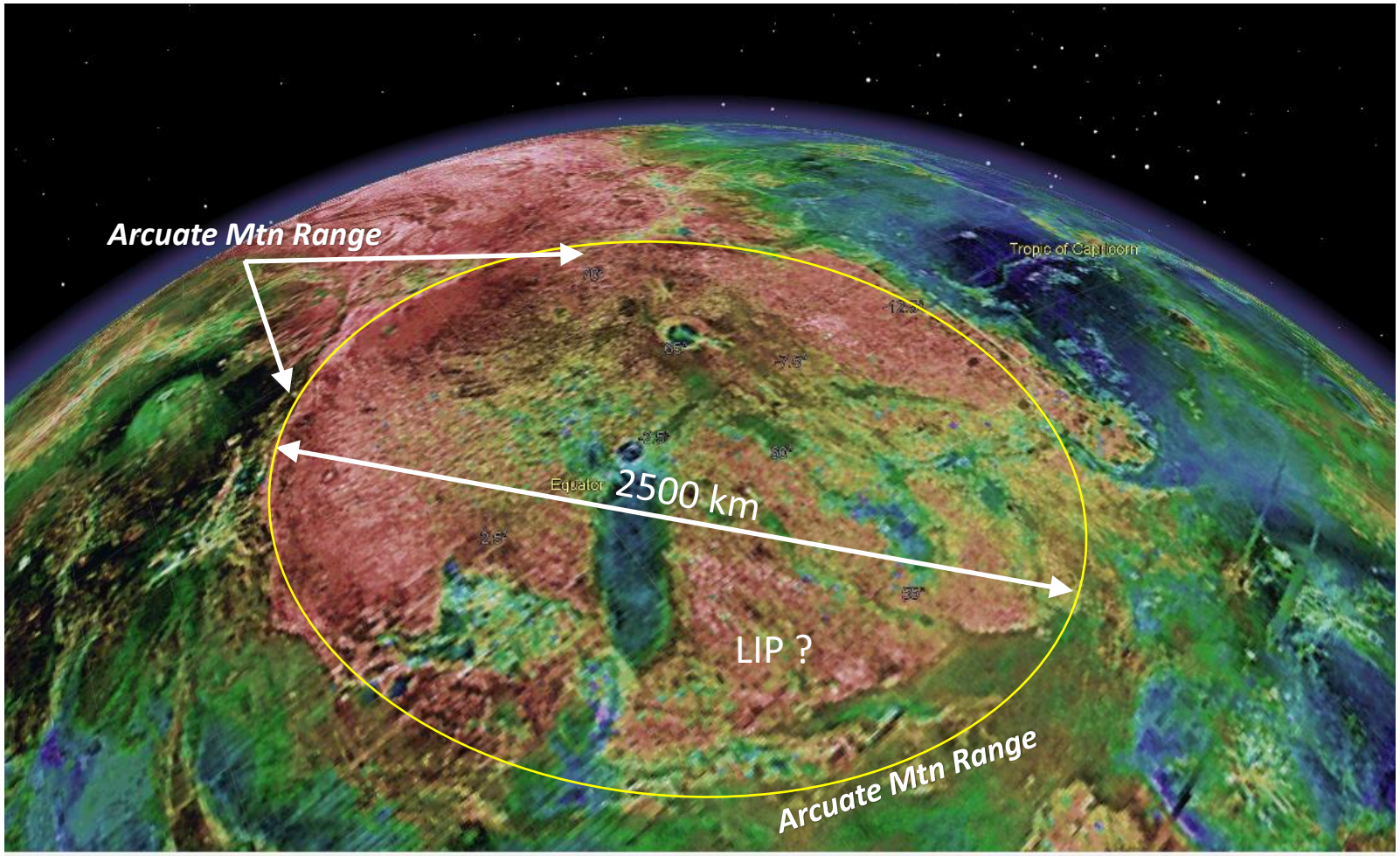
Cook Inlet regional 2D seismic.



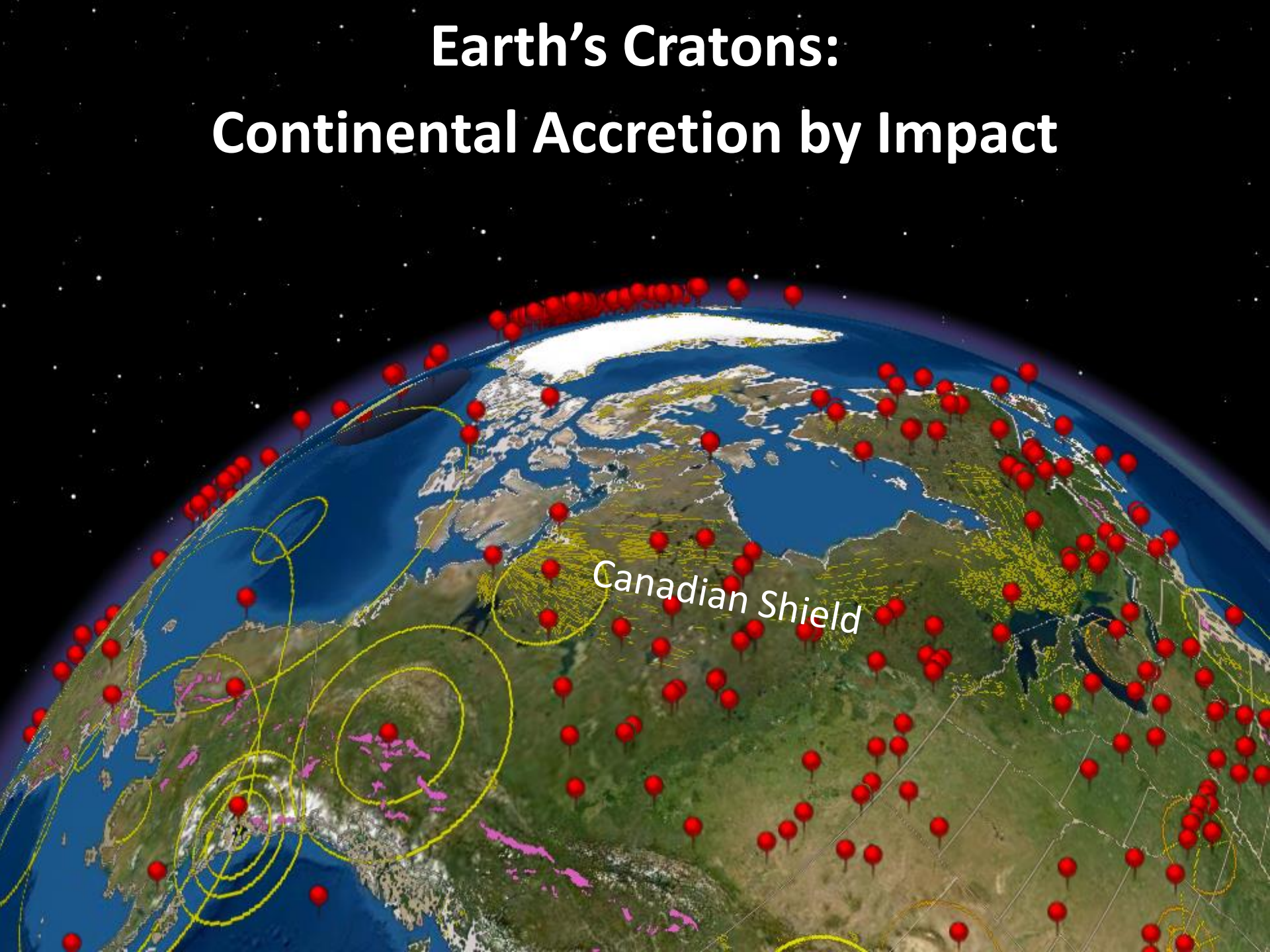

Petroleum reservoir parameters exhibited in large multi-ringed craters.

D. Buthman 8/23/2018

# North Slope Exploration Model Venus



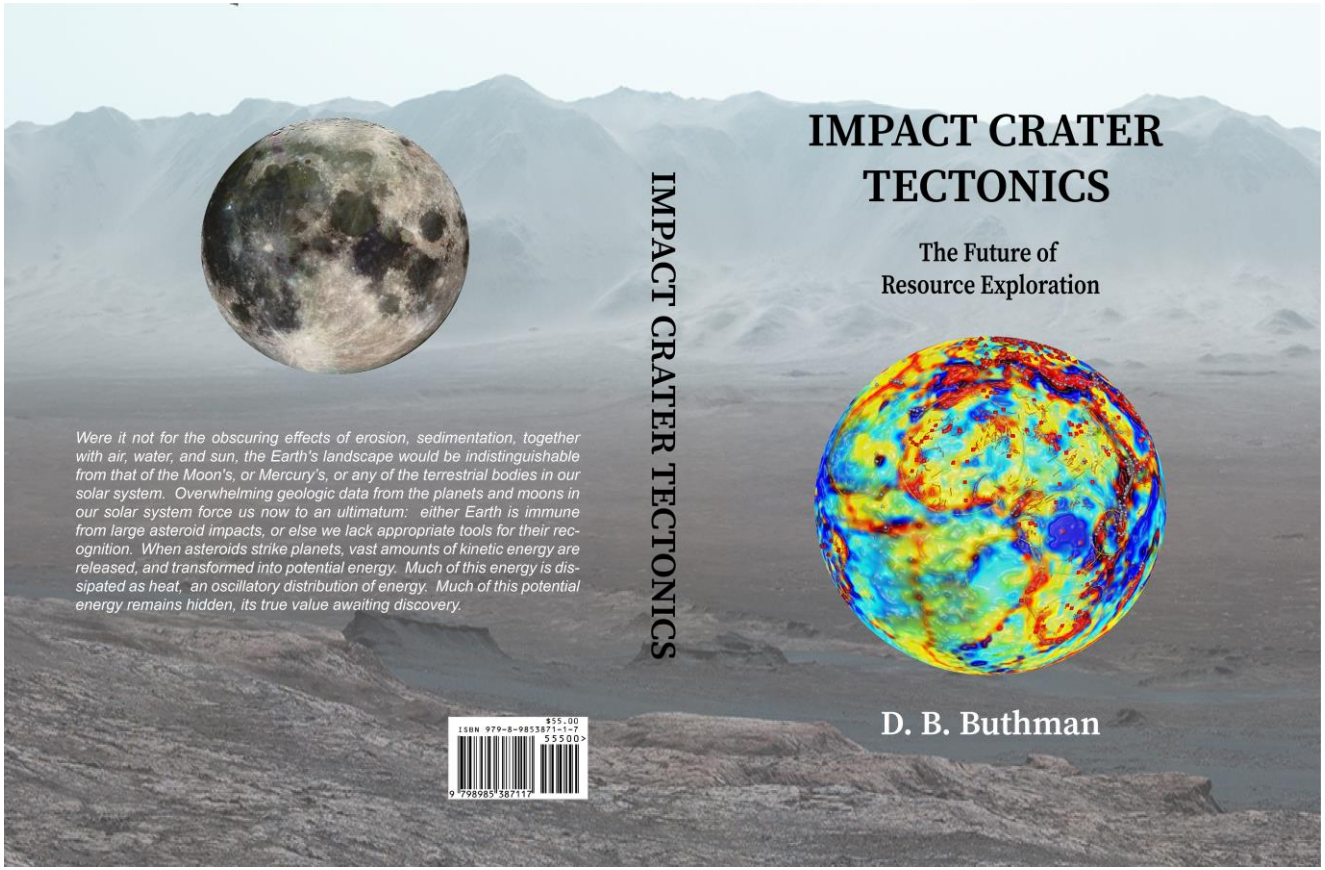
# Earth's Cratons:
# Continental Accretion by Impact



# OIL & GAS FIELDS PROVEN FROM IMPACT CRATERS

| IMPACT CRATER FIELD | LOCATION | DIAMETER, KM | AGE | FIELD SIZE |
|---|---|---|---|---|
| Ames | Major Co., OK | 14 | E. Ordovician 470 Ma | 18 MMBO + 20 BCFG |
| Avak | Point Barrow, AK | 12 | Cetaceous-Tertiary | 37 BCFG |
| Boltysh Depression | Ukraine | 24 | 65.8 Ma | "several billion barrels" |
| Calvin | Cass County, MI | 7.24 | Lower Ordovician | 600 MBO CUM |
| Cantarel (Chicxulub) | Yucatan Peninsula, Mexico | 300 | Cretaceous-Tertiary | Reserves: 45,000 MMBO |
| Hartney | Manitoba, Canada | 11.2 | 190 Ma | |
| Haswell Hole | Colorado | 35 | 1400 Ma | Morrow production |
| Lyles Ranch | Zavala Co., TX | 4 | Lower Tertiary | 2 BCFG |
| Marquez | Leon Co., TX | 12.7 | Early Tertiary | 54 BCFG |
| Newporte | Renville Co, N.D. | 3.2 | Cambrian-Ordovician | 15 MMBO |
| Red Wing Creek | McKenzie Co., N.D. | 9 | Jurassic-Triassic; 190 Ma | 10 MMBO |
| Sheeva Crater | Surat Basin, India (Bombay) | | 65 Ma | 8.4 BBbls oil + 24.2 TCFG |
| Sierra Madera | Pecos Co, tX | 13 | Lower Cretaceous | 270 BCFG |
| Steen River | NW Alta., Canada | 25 | Middle Cretaceous | 50 MMBO |
| Viewfield | SE Sask., Canada | 3.2 | Early Jurassic | Cumulative 20 MMBO |

# Questions?
# ImpactCraterStudies.org

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