Predicting Sedimentary Facies in the Gulf of Mexico Region from the Combination of Bathymetry, Gravity, and Magnetic Data Using Fractal Geometry

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ABSTRACT

Lamb et al. (2004) identified from flume experiments four regimes of deposition, mathematically described by a Ponding Index (Po): (1) a perfectly ponded deposit, (2) a mounded deposit, (3) a perfectly draped deposit, and (4) a deposit with accentuated highs. This study extends Lamb's laboratory results to basin scale architecture by using bathymetry, gravity, and magnetics combined with fractal geometry to predict the same four sedimentary facies in the Gulf of Mexico region.

Turcotte (1992) first published *Fractals and Chaos in Geology and Geophysics* 25 years ago. Data that exhibit power-law spectra, such as bathymetry, gravity, and magnetics, are suitable for the application of fractal geometry. The fractal dimension of the combination of bathymetry and gravity (FDBG) identifies a preferred depositional pattern working from the top down through geologic time. Likewise, combining magnetics and gravity with fractal geometry (FDMG) identifies a preferred depositional pattern working from the bottom up through geologic time. Taking the ratio FDBG/FDMG yields a Ratio Index (Ro) map similar to Lamb's Po.

After 70 years of drilling in the Gulf of Mexico, many fields correlate well with Ro. The expanded Miocene discoveries (e.g., Thunderhorse) in the deepwater Gulf of Mexico are examples of ponded deposits. There are also several large mounded deposit fields (e.g., Mars). This study presents an Ro map over the Gulf of Mexico showing the four sedimentary facies identified in the Lamb et al. (2004) paper. Examples of all four depositional regimes are shown on several 2D seismic lines (GulfSPAN). The study area extends down to the Yucatan Peninsula where Ro shows a diagnostic footprint of the Chicxulub Impact. The study thus discusses other possible impact sites in the Gulf of Mexico based on Ro.

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09.19.2016

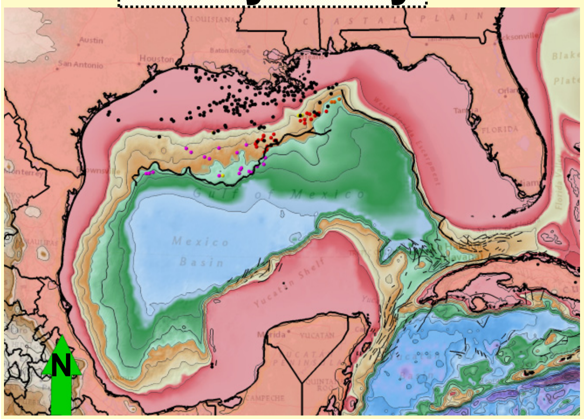
PREDICTING SEDIMENTARY FACIES

IN THE GOM REGION FROM THE COMBINATION OF BATHYMETRY, GRAVITY, AND MAGNETICS USING FRACTAL GEOMETRY

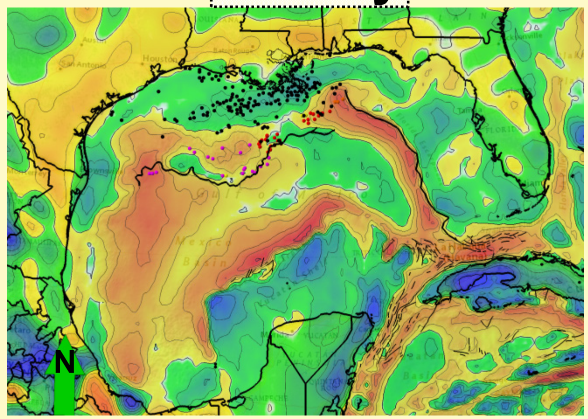
VICTOR J. MISTRETTA

PREDICTING SEDIMENTARY FACIES
IN THE GoM REGION FROM THE COMBINATION OF

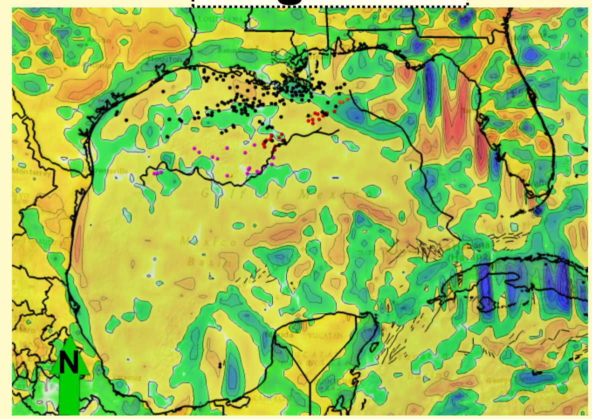
Bathymetry



Gravity



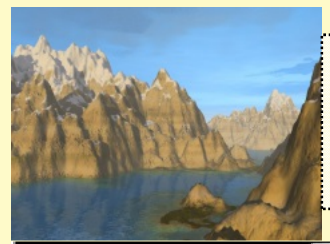
Magnetics



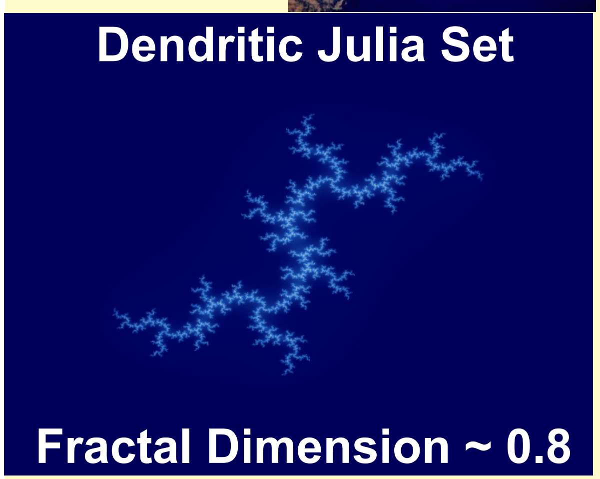
Gentle Fractal Landscape

Using

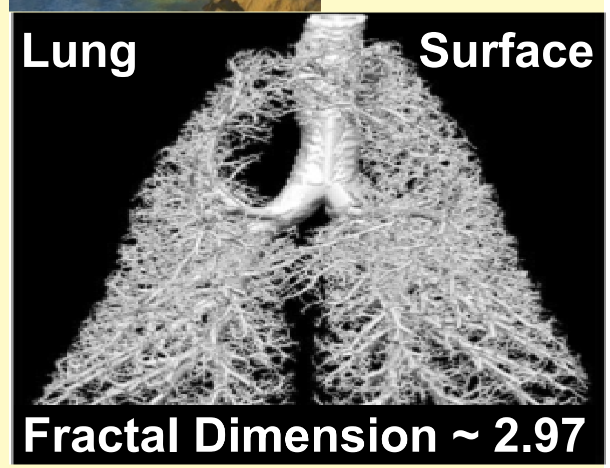
FRACTAL GEOMETRY



Rugged Fractal Landscape



A Fractal is a nonlinear geometric object with an infinite nesting of facsimile structures at all scales (from outcrop to thin section).

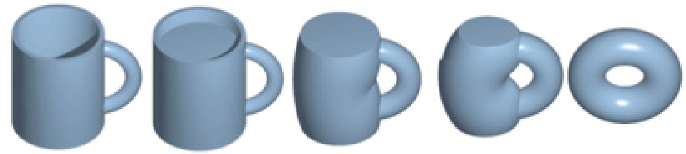


DENDRITIC DRAINAGE PATTERNS

BUILDING A FRACTAL DRAINAGE NETWORK

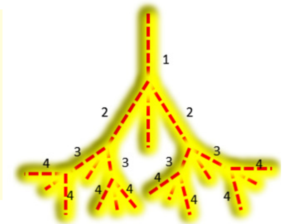
$N_n = C/(r_n)^D$ => $D = \ln (N_{n+1}/N_n)/\ln (r_n/r_{n+1})$ Donald Turcotte "Fractals and Chaos in Geology and Geophysics"

Where N = # of Objects, C = Constant of Proportionality,
r = Size or Linear Dimension, and D = Fractal Dimension.



ASSUMPTIONS: (A) Linear Dimension of the Drainage Network is Represented by All Paleobathymetries (PB).
(B) Ratio of Successive Paleobathymetries is constant insuring scale invariance.

After Time 1 ~ 1 Object
After Time 2 ~ 2 Objects
After Time 3 ~ 4 Objects
After Time 4 ~ 8 Objects
…etc… Thus
$N_{n+1}/N_n = 2$ where N = # of Objects



Thus from (A)	(1)	$r_n = PB_0 + PB_1 + PB_2 + PB_3 \ldots$
And from (B)	(2)	$r = PB_0/PB_1 = PB_1/PB_2 = PB_2/PB_3 \ldots$
Substitution into (1)	(3)	$r_n = PB_0 + PB_0/r + PB_0/r^2 + PB_0/r^3 + \ldots$
Factoring (3)	(4)	$r_n = PB_0 r\ [1/r + 1/r^2 + 1/r^3 + \ldots]$
Geometric Series […]	(5)	with $a_1 = 1/r$, $a_n = 1/r^n$, $c = 1/r$ (common ratio), and n number of terms
Hence	(6)	$S_n = (1/r\ (1-1/r^n))/(1-1/r)$
And	(7)	$\lim_{n=>\sim} S_n = 1/r/(1-1/r) = 1/(r-1)$
Substitution into (4)	(8)	$r_n = PB_0 r/(r-1)$
Likewise	(9)	$r_{n-1} = PB_1 r/(r-1)$
Hence	(10)	$\ln (r_n/r_{n+1}) = \ln ((PB_1 r/(r-1)) \times ((r-1)/(PB_0 r)) = \ln (PB_1/PB_0)$
Therefore	(11)	$D = (\ln(2))/(\ln(PB_1/PB_0))$

Mississippi River Delta

Iterating Paleobathymetries at Major Geologic Ages was complex and produced unfavorable results because of a paucity of input points. Gravity is tacitly a collage of all Paleobathymetries. This assumption reduced the above algorithm to a very simple formula.

$$\boxed{\begin{gathered} FDBG = (\ln(2))/(\ln(B+C/G+C')) \\ FDMG = (\ln(2))/(\ln(M/G)) \end{gathered}}$$

DEPOSITIONAL REGIMES

LABORATORY STUDY OF TURBIDITY CURRENTS

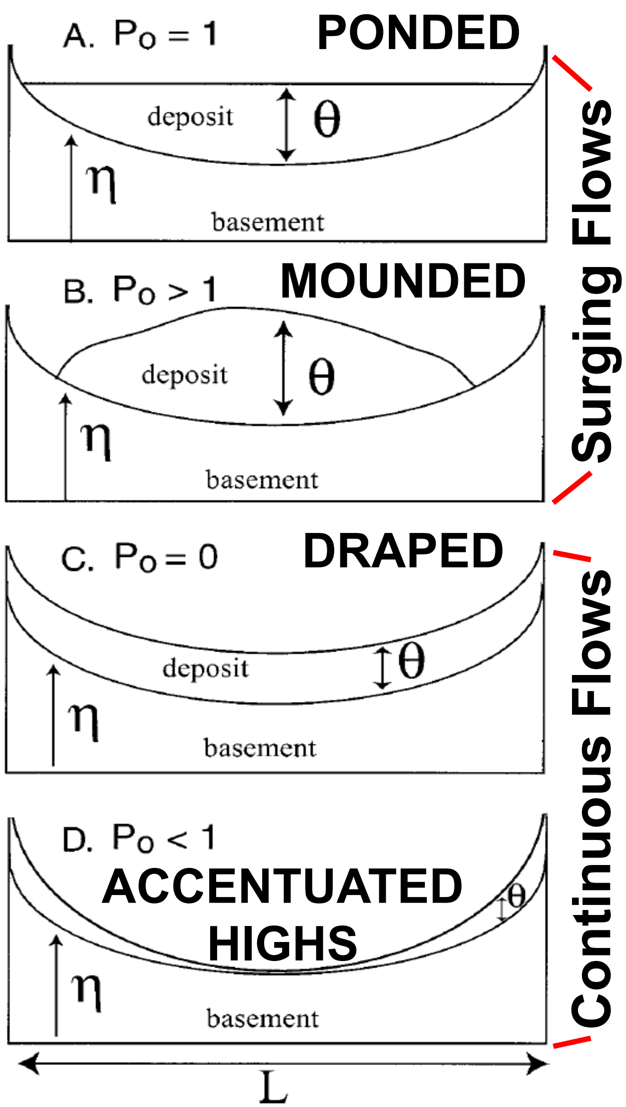
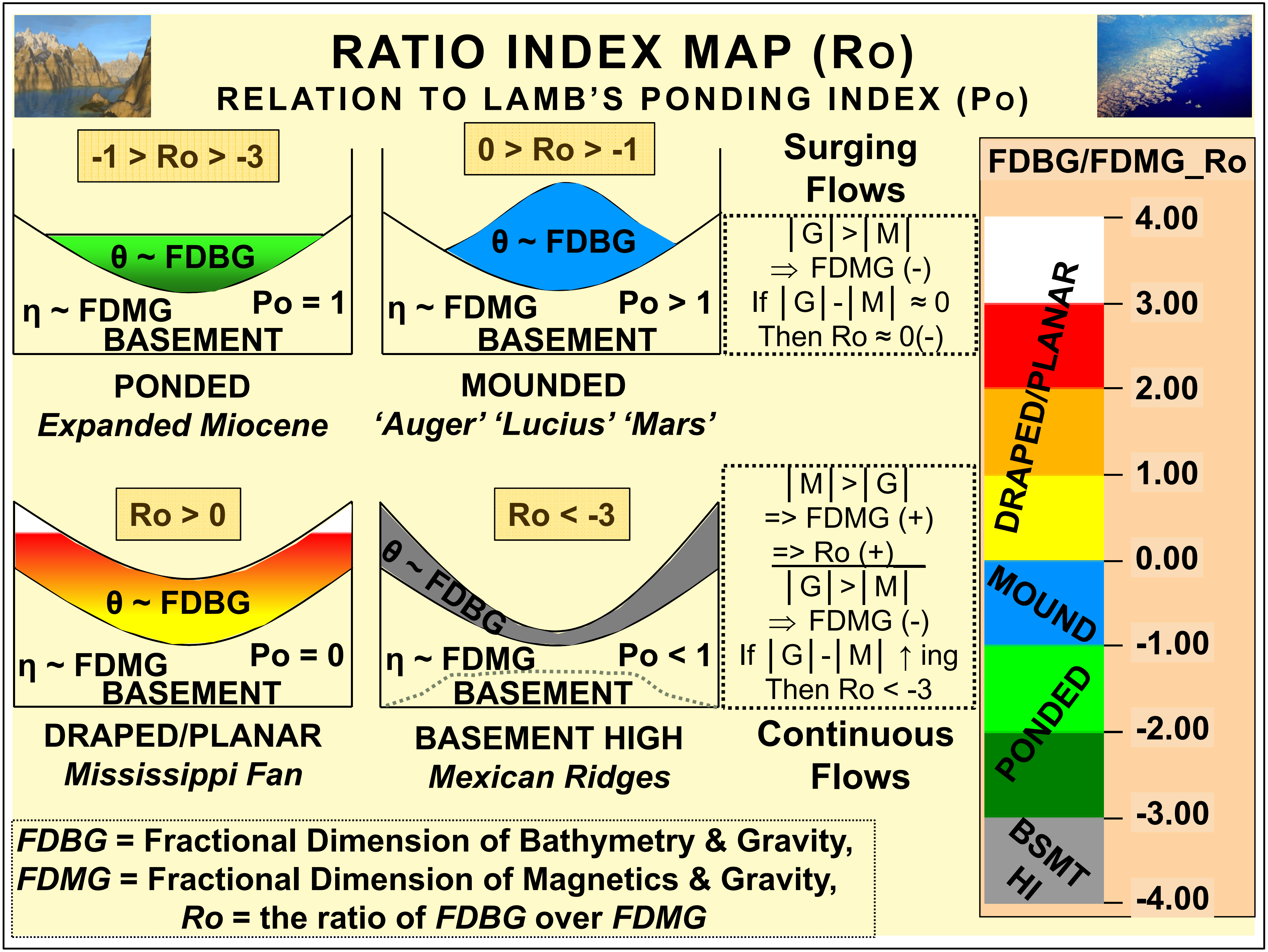


FIG. 4.—Four regimes of deposition described by the deposit ponding index are **A)** a perfectly ponded deposit: Po = 1, **B)** a mounded deposit: Po > 1, **C)** a perfectly draped deposit: Po = 0, and **D)** a deposit with accentuated highs: Po < 0.

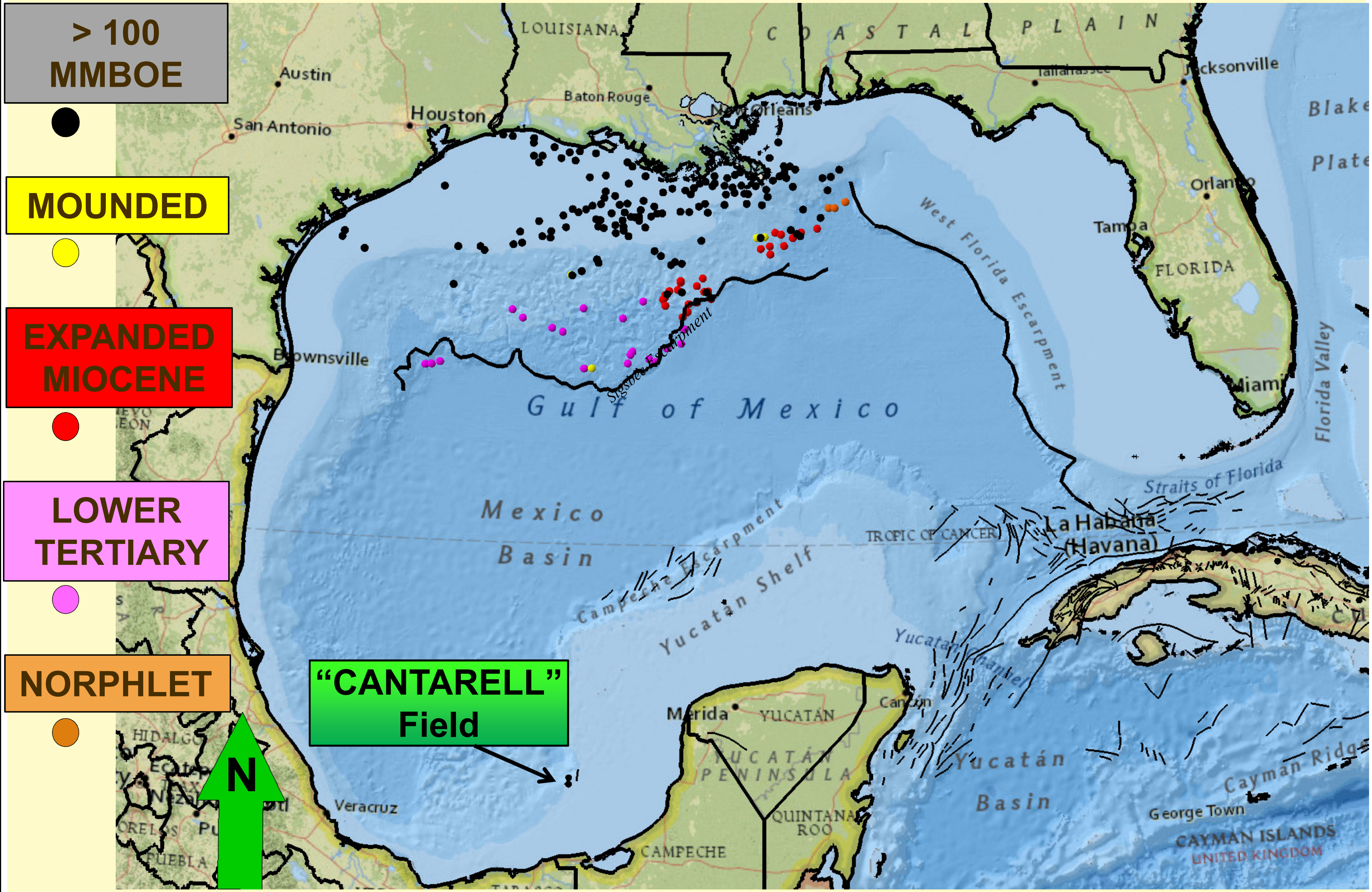
Michael P. Lamb, et al Journal of Sedimentary Research, 2004

$$\mathrm{Po} = -\frac{1}{L}\int_0^L \frac{d\theta}{d\eta}\,dx$$

Where x is the downdip coordinate, L denotes the streamwise length of the basin, *θ(x)* denotes the thickness of the deposit and *η(x)* denotes the elevation of the initial bed. A deposit ponding index equal to one represents a completely ponded deposit (Fig. 4A), a deposit ponding index greater than unity represents a mounded deposit (Fig. 4B), and a deposit ponding index equal to zero represents a purely draped deposit (Fig. 4C). A deposit with accentuated highs, meaning that the flow deposits preferentially on the slopes rather than the center of the basin, would have a negative deposit ponding index (Fig. 4D).

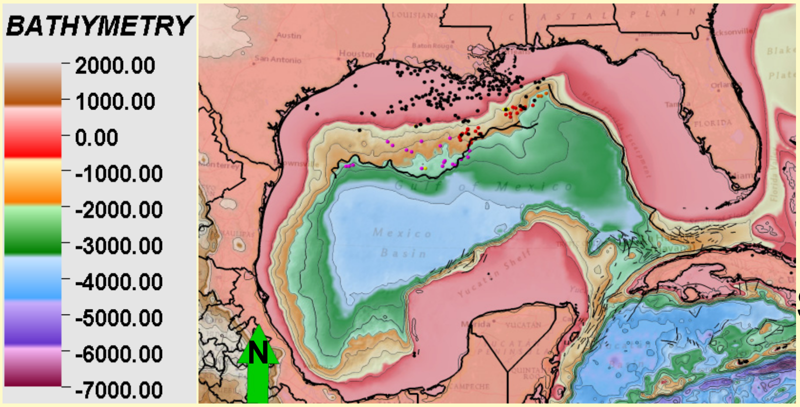

RATIO INDEX MAP (Ro)
RELATION TO LAMB'S PONDING INDEX (Po)
-1 > Ro > -3
θ ~ FDBG
η ~ FDMG
Po = 1
BASEMENT
PONDED
Expanded Miocene
0 > Ro > -1
θ ~ FDBG
η ~ FDMG
Po > 1
BASEMENT
MOUNDED
'Auger' 'Lucius' 'Mars'
Surging Flows
|G|>|M|
⇒ FDMG (-)
If |G|-|M| ≈ 0
Then Ro ≈ 0(-)
Ro > 0
θ ~ FDBG
η ~ FDMG
Po = 0
BASEMENT
DRAPED/PLANAR
Mississippi Fan
Ro < -3
θ ~ FDBG
η ~ FDMG
Po < 1
BASEMENT
BASEMENT HIGH
Mexican Ridges
|M|>|G|
=> FDMG (+)
=> Ro (+)
|G|>|M|
⇒ FDMG (-)
If |G|-|M| ↑ ing
Then Ro < -3
Continuous Flows
FDBG/FDMG_Ro
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
DRAPED/PLANAR
MOUND
PONDED
BSMT HI
FDBG = Fractional Dimension of Bathymetry & Gravity,
FDMG = Fractional Dimension of Magnetics & Gravity,
Ro = the ratio of FDBG over FDMG

GULF OF MEXICO STUDY AREA
SIGNIFICANT FIELDS IN US WATERS



FRACTAL COMBINATION (FDBG)

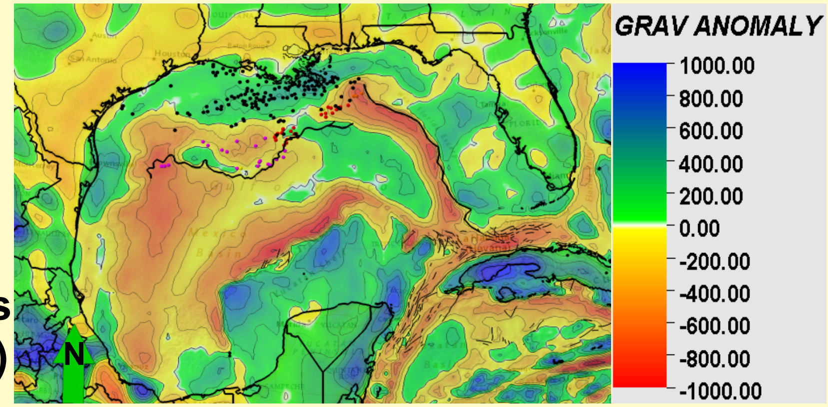
BATHYMETRY AND GRAVITY

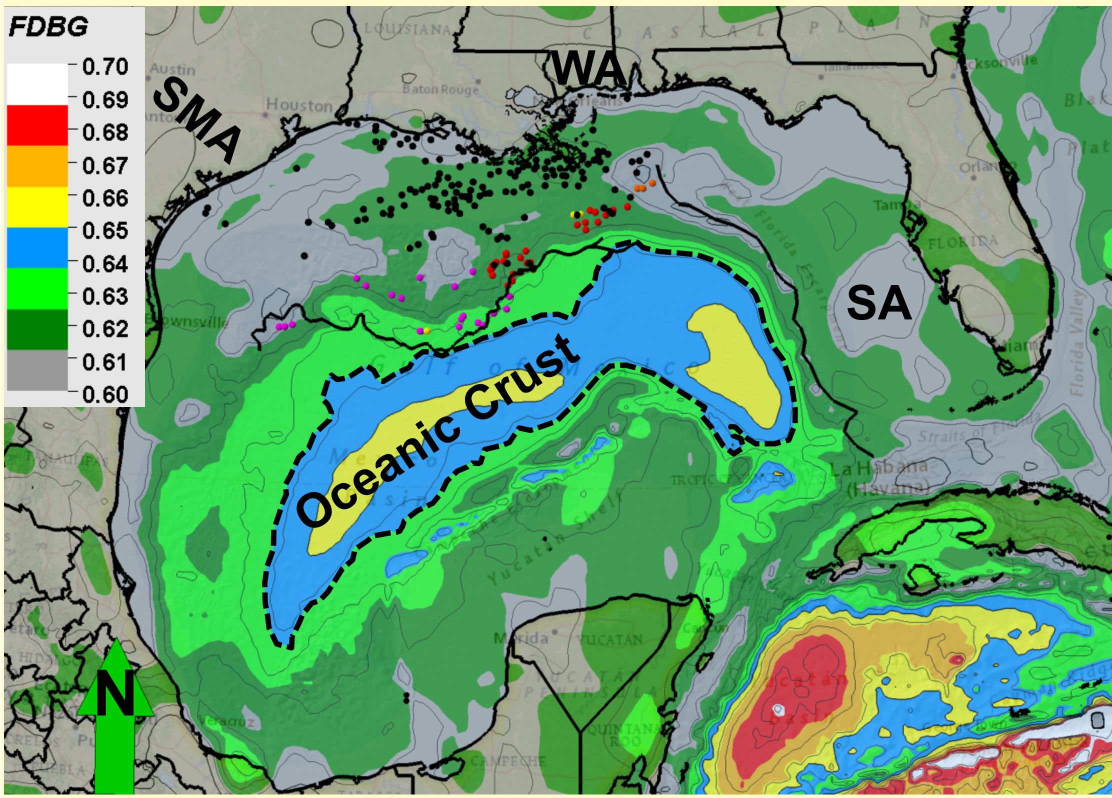


Wiggins Arch (WA)

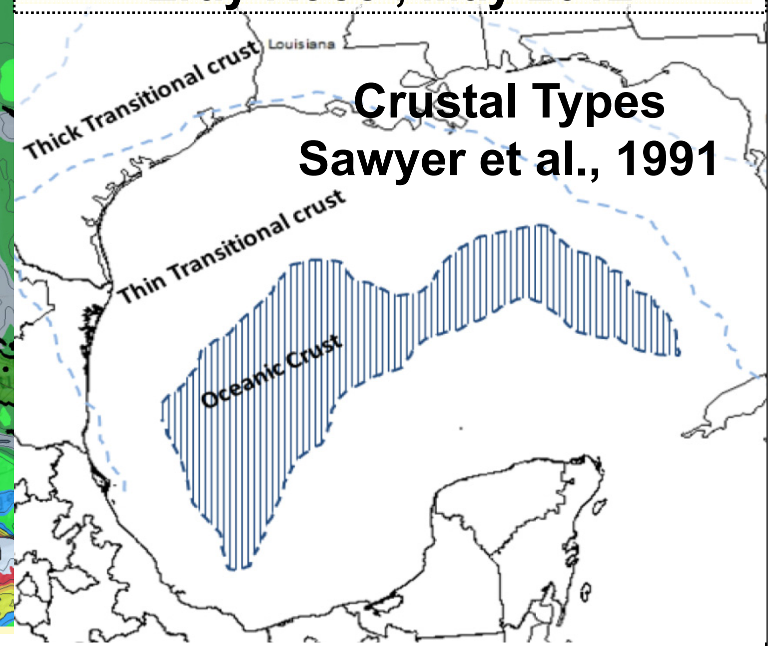
Sarasota Arch (SA)

San Marcos Arch (SMA)



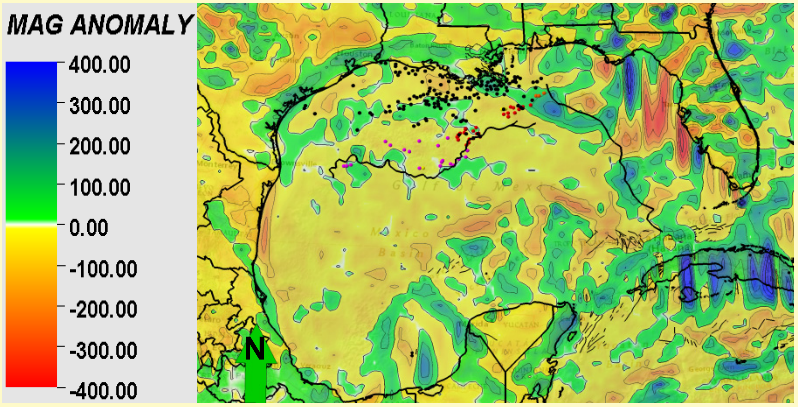


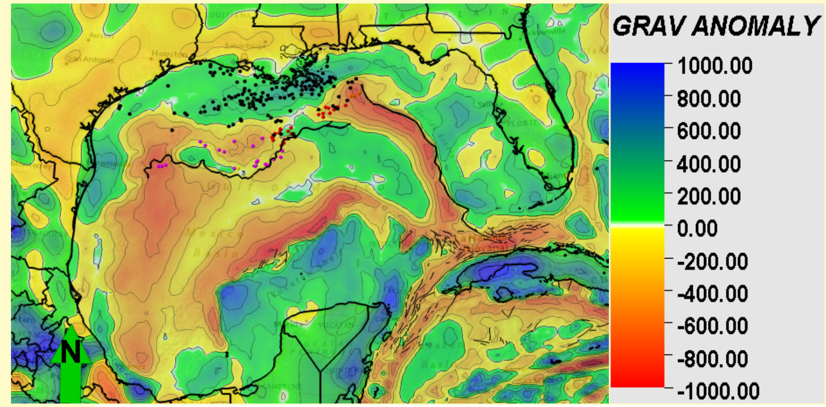
An Integrated Geophysical Study of the Northern GoM
Eray Kocel, May 2012

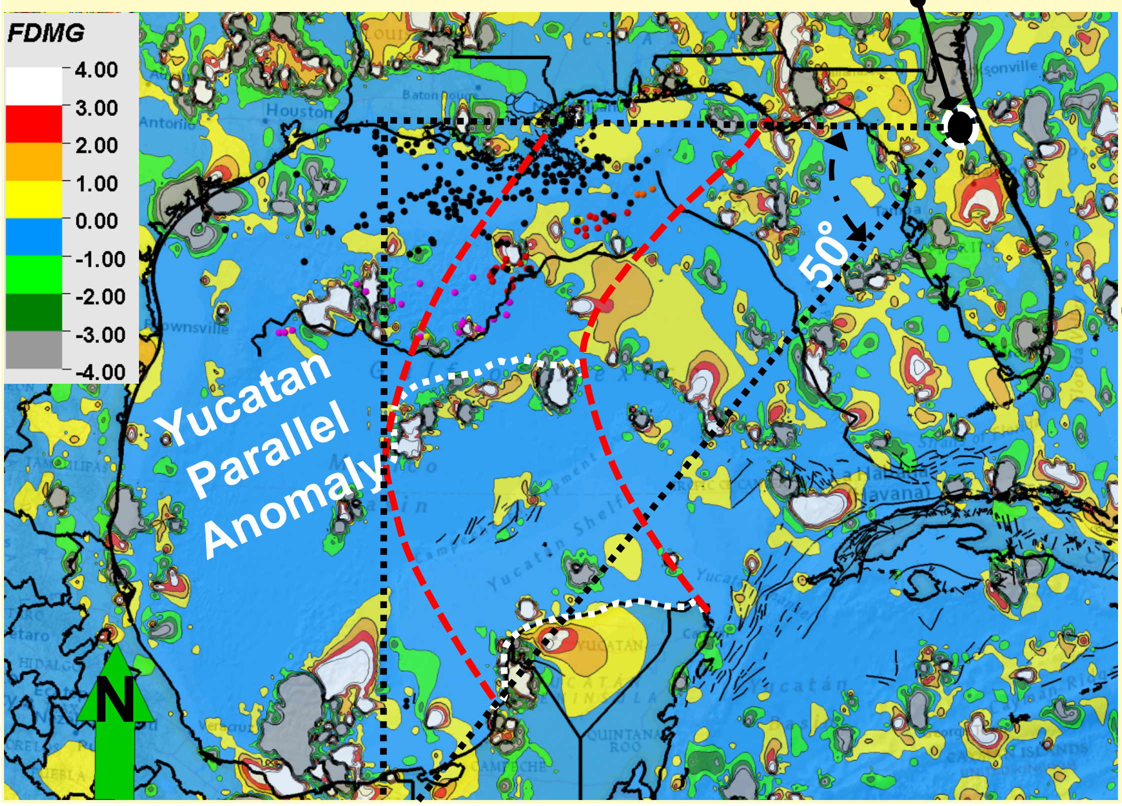


FRACTAL COMBINATION (FDMG)

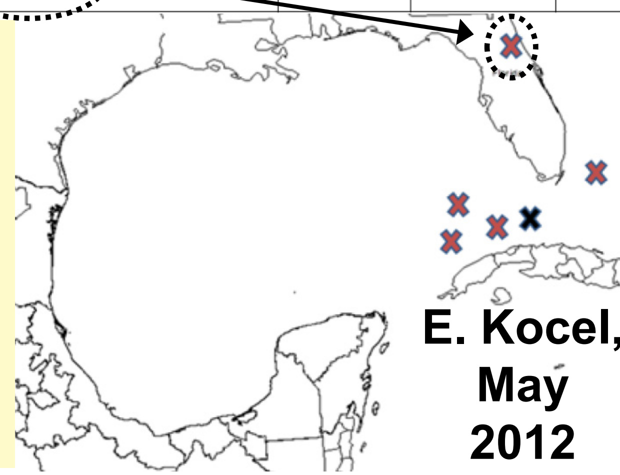
MAGNETICS AND GRAVITY







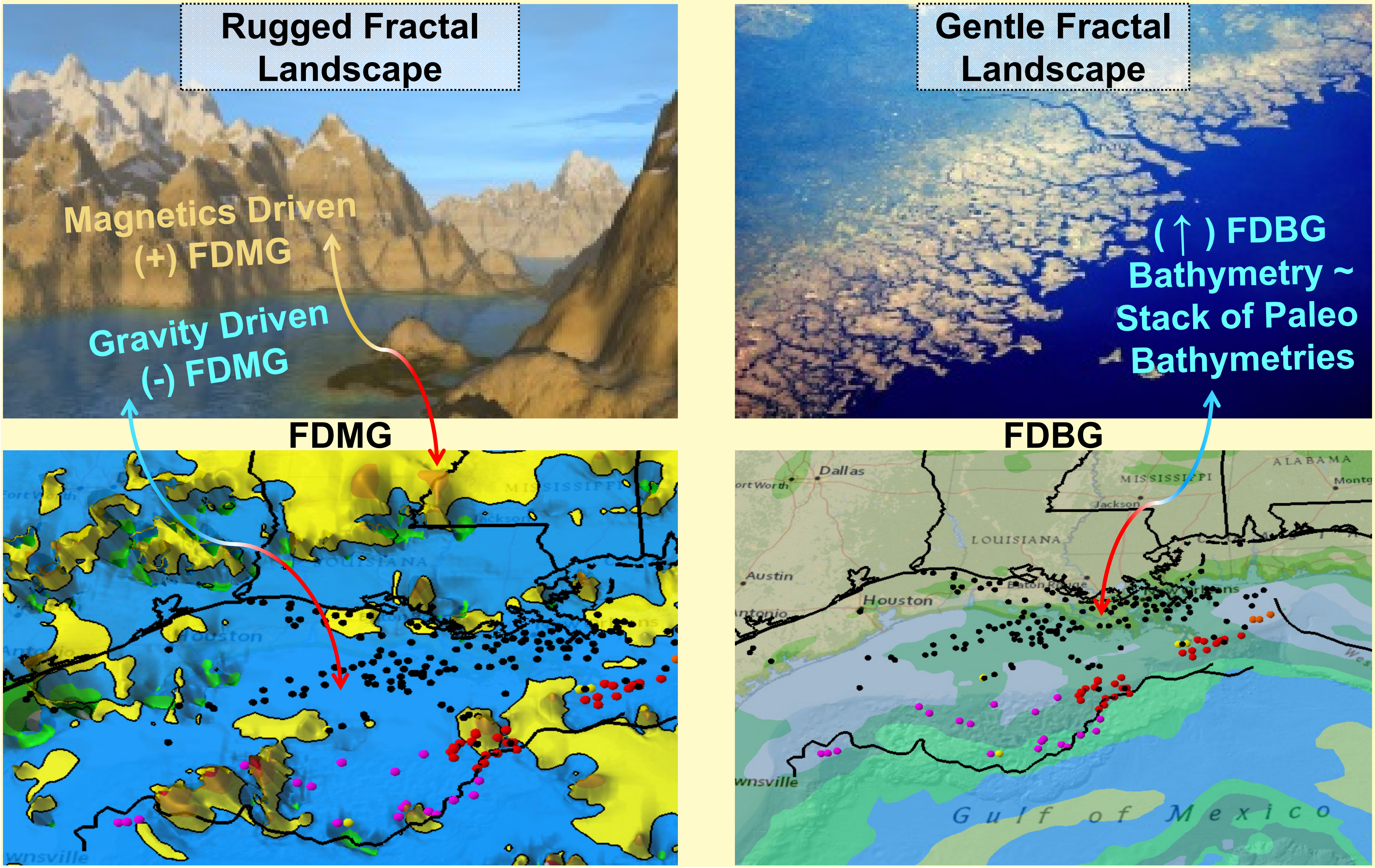
	Latitude	Longitude	Rotation
Dunbar and Sawyer, 1987	25.00	-79.00	45°
Hall and Najmuddin,1994	24.00	-81.5	55°
Shepherd,1983	24.00	-84.0	41°
Bird et al..,2005	24.00	-81.5	42°
Pindell, 1985	29.5	-81.4	43°



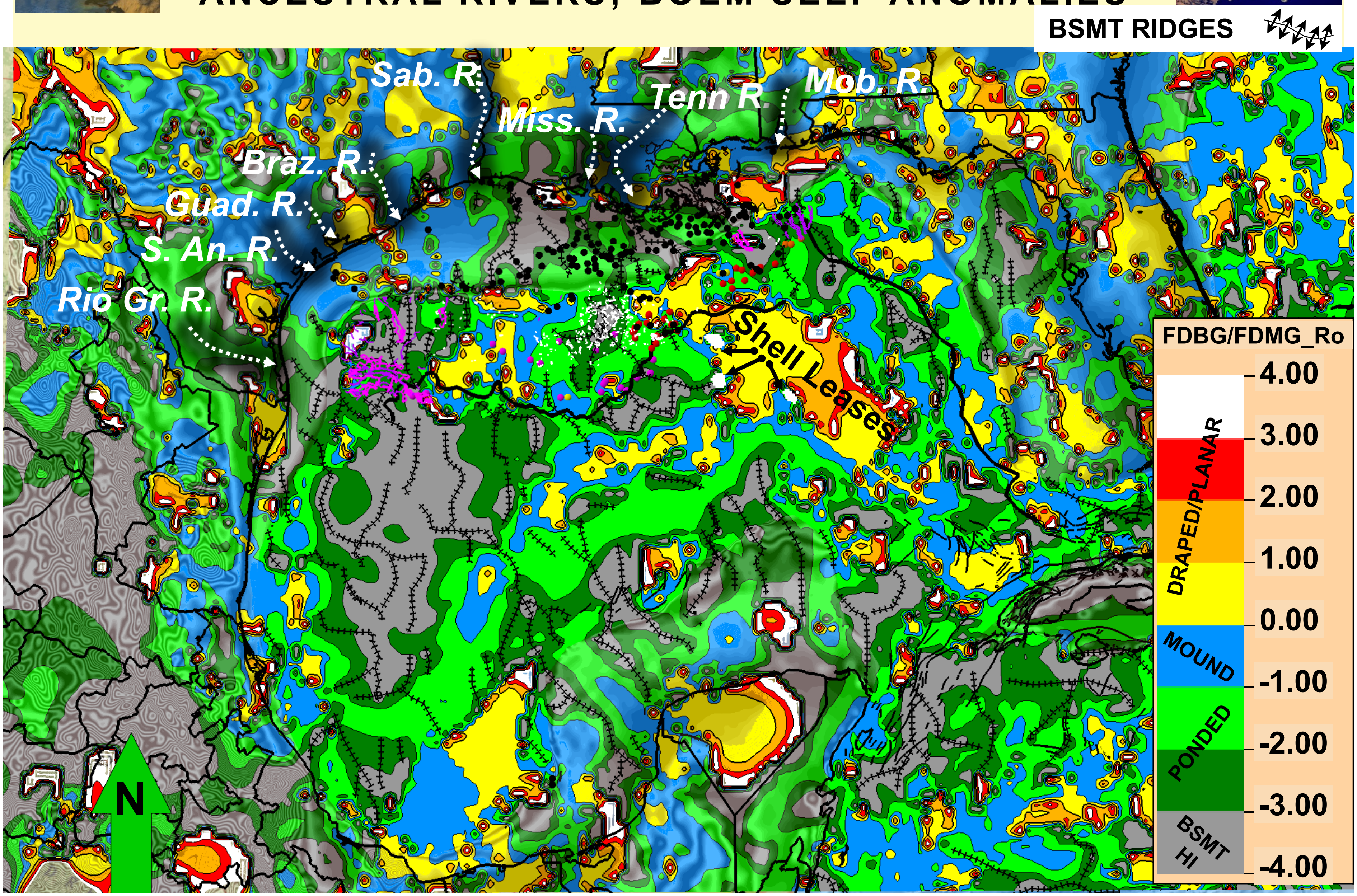
E. Kocel, May 2012

(FDMG) & (FDBG)

COMPARED TO FRACTAL LANDSCAPES



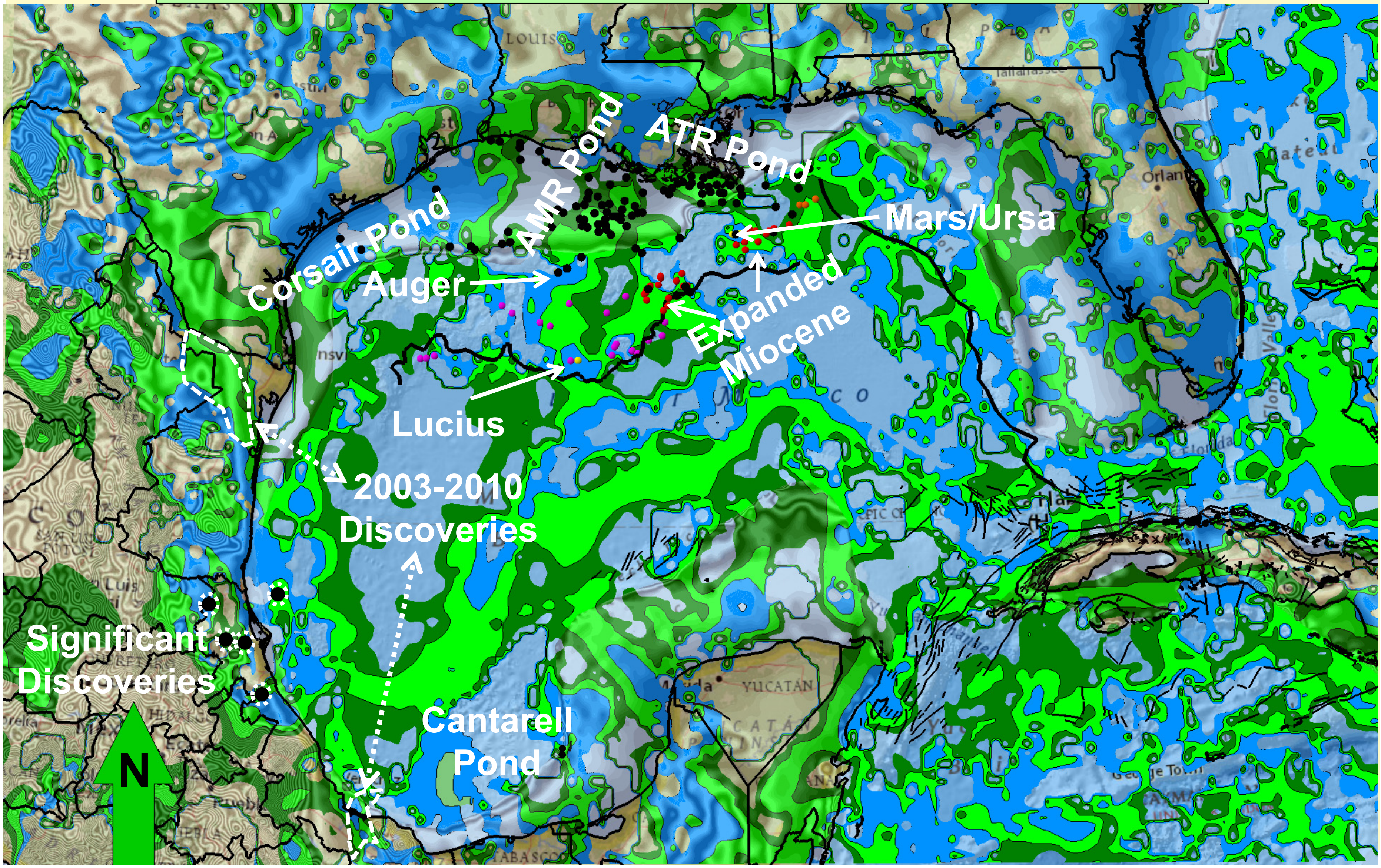
(Ro) RATIO OF FDBG OVER FDMG
ANCESTRAL RIVERS; BOEM SEEP ANOMALIES



MOUNDED & PONDED FACIES

Ro BETWEEN 0 AND -3

- *103 FIELDS (~77 %) with Current Production > 100 MMBOE*



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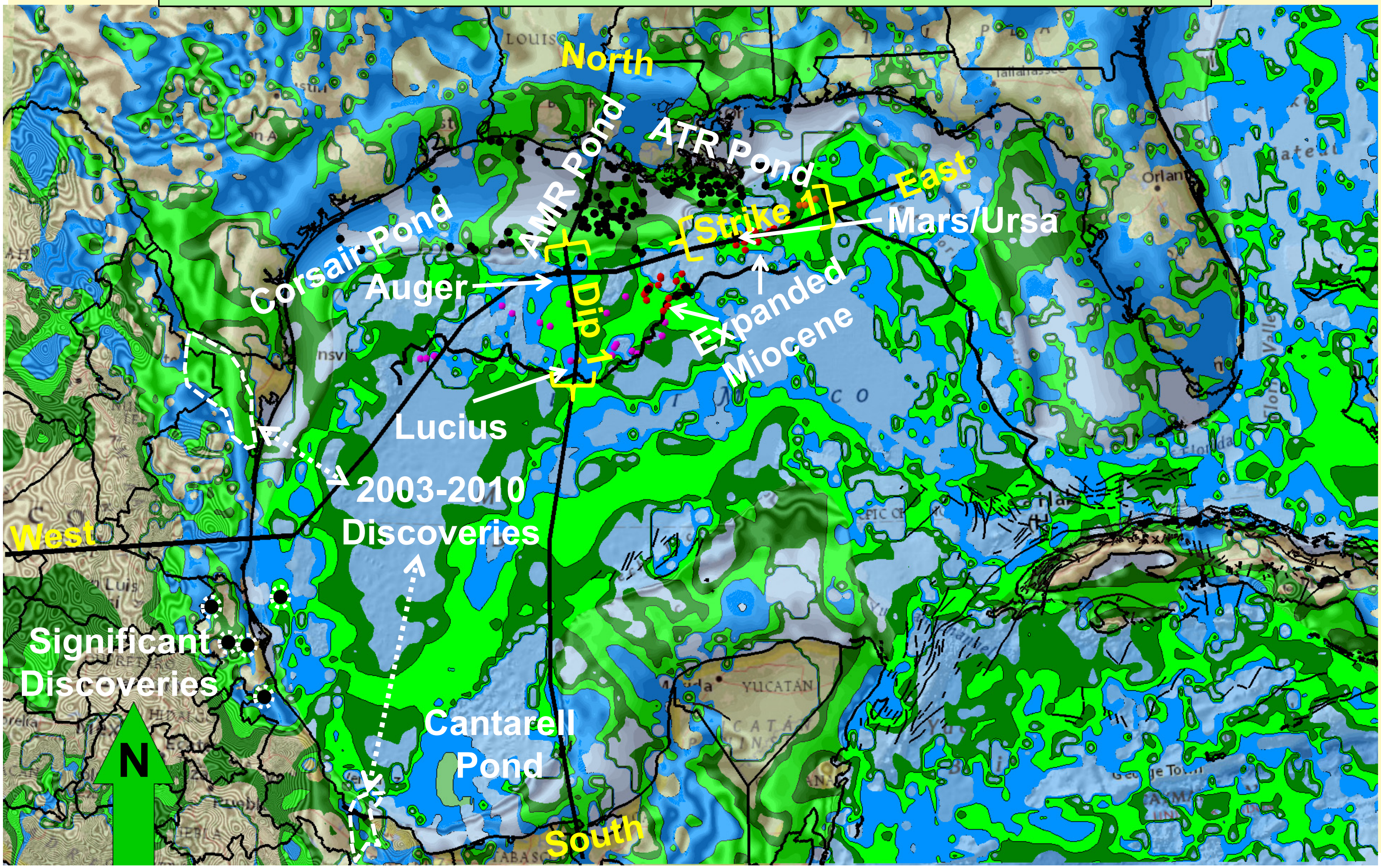
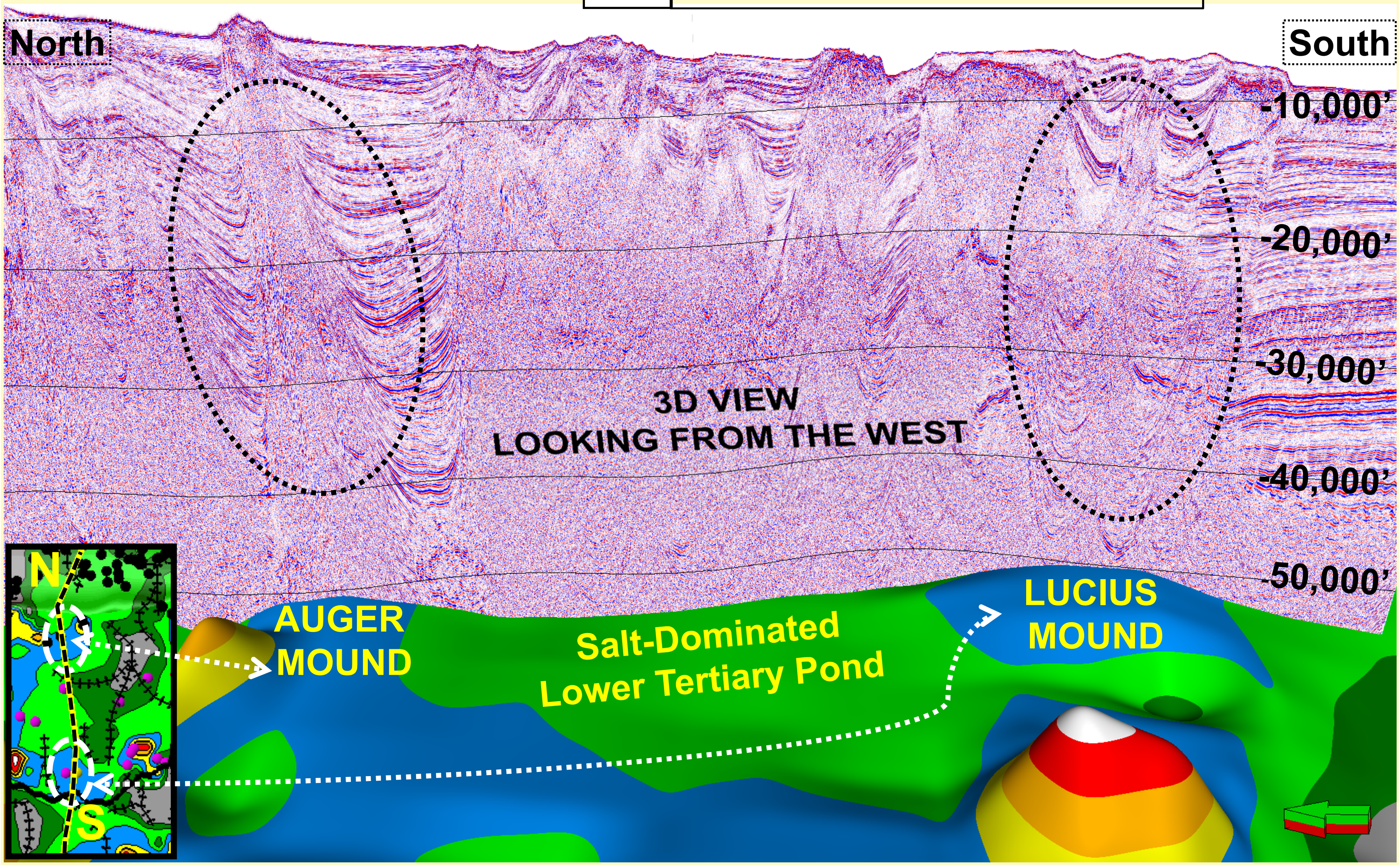


GULFSPAN 2D (PSDM) 2003/04 VINTAGE

DIP 1

Courtesy of ION Geophysical

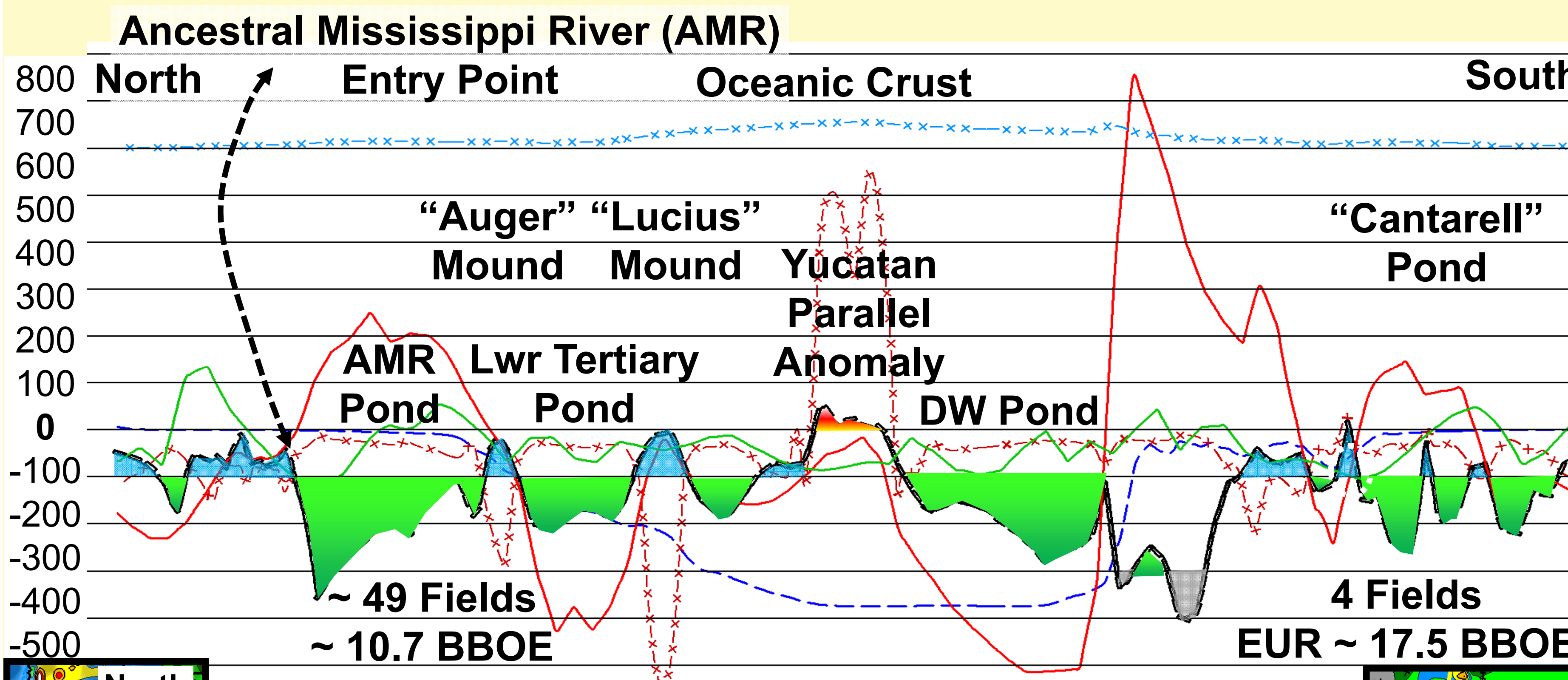


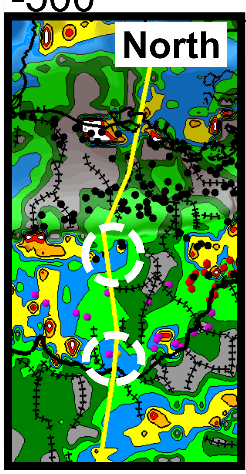
Ro SCALED FOR SEISMIC

Vertical Exaggeration ~ 7.5 to 1

VERTICAL INTERSECTION

EXTENDED ALONG & BEYOND DIP1 LINE





AMR Pond

"Auger" Mound

Lwr Tertiary Pond

"Lucius" Mound

Yucatan II Anomaly

Gravity Anomaly

Magnetic Anomaly

Bathymetry / 10 (Mtr) - - -

*FDBG * 1000 x-x-x*

*FDMG * 100 x-x-x*

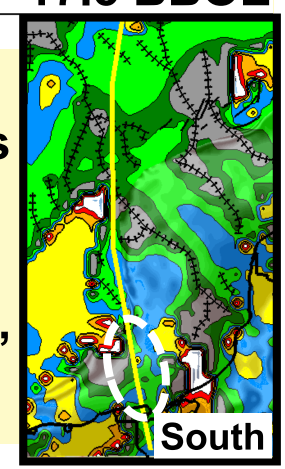
*Ro * 100*

DW Pond

Mexican Waters

"Cantarell"

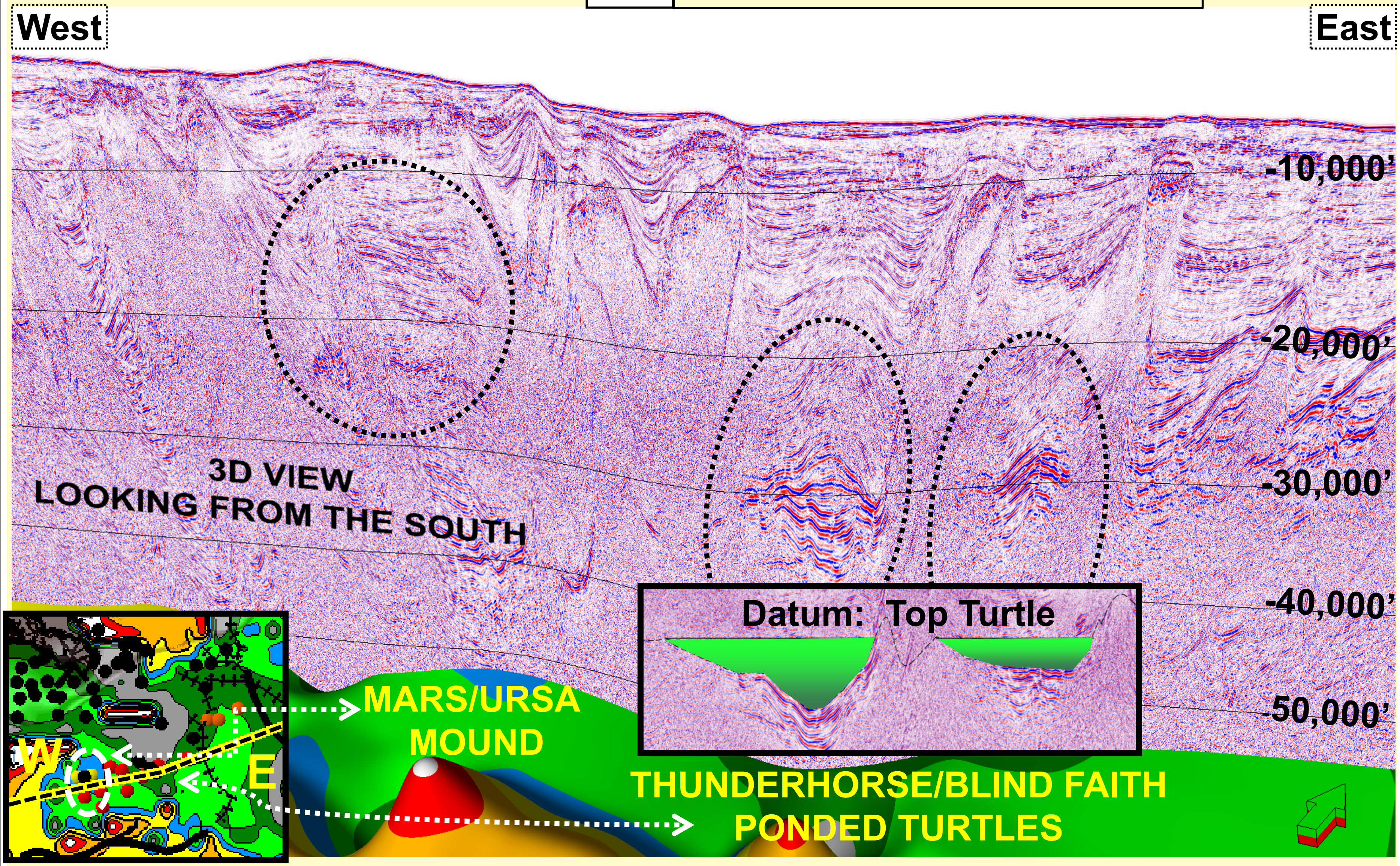
Pond



GULFSPAN 2D (PSDM) 2003/04 VINTAGE

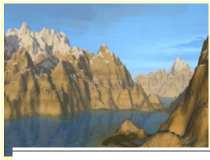
STRIKE 1

Courtesy of ION Geophysical



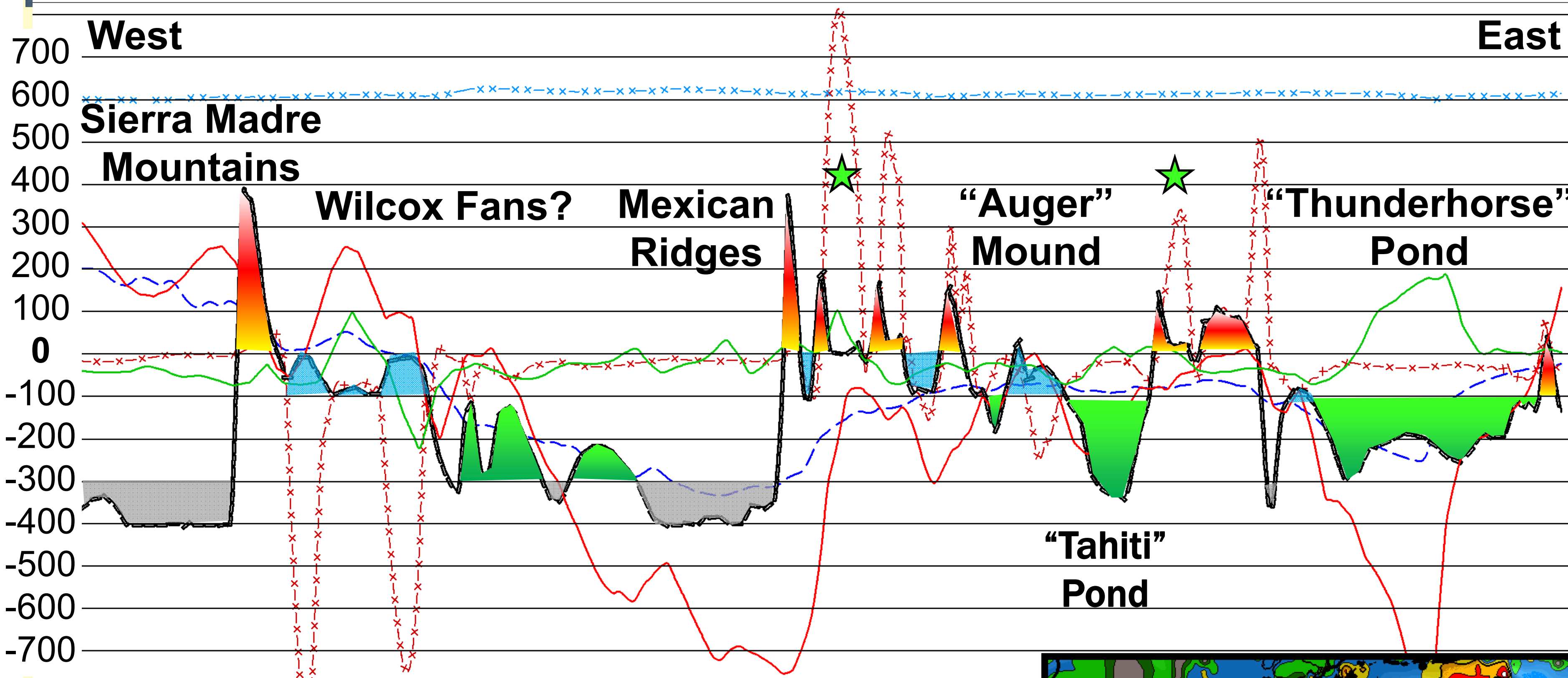
Ro SCALED FOR SEISMIC

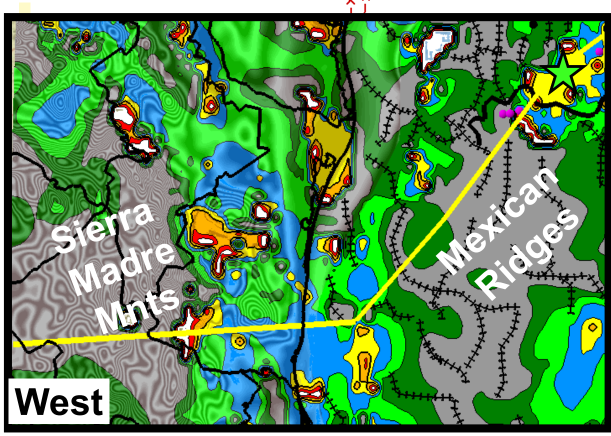
Vertical Exaggeration ~ 7.5 to 1



VERTICAL INTERSECTION

EXTENDED ALONG & BEYOND STRIKE1 LINE





Gravity Anomaly

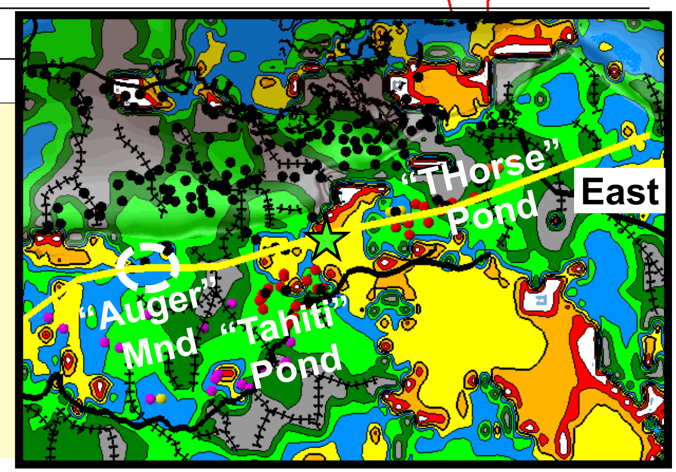
Magnetic Anomaly

Bathymetry / 10 (Mtr) - - -

*FDBG * 1000 x-x-x*

*FDMG * 100 x-x-x*

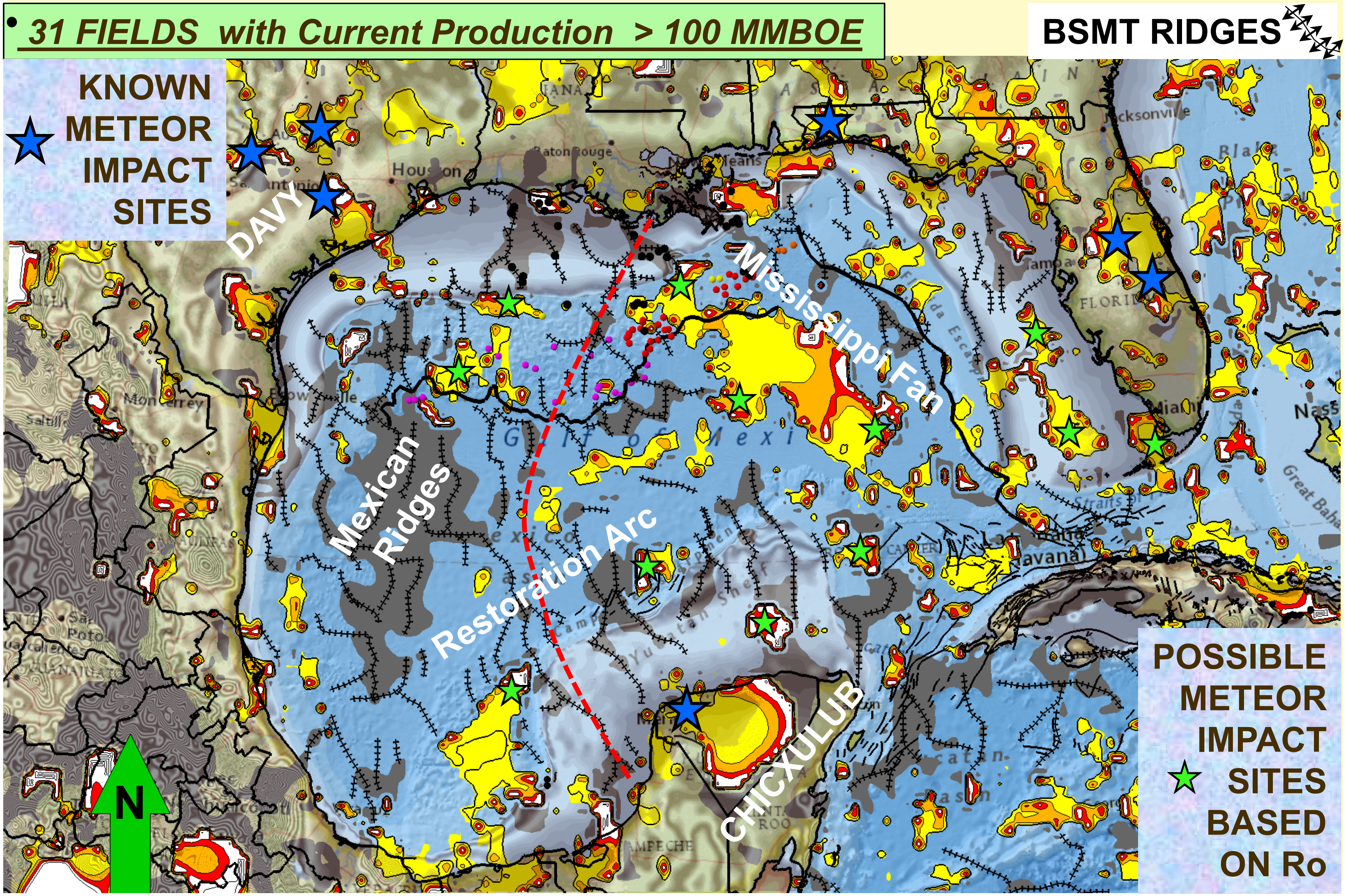
*Ro * 100*



BSMENT HIGHS & PLANAR FACIES

Ro LESS THAN -3 & Ro >0

• ***31 FIELDS with Current Production > 100 MMBOE***

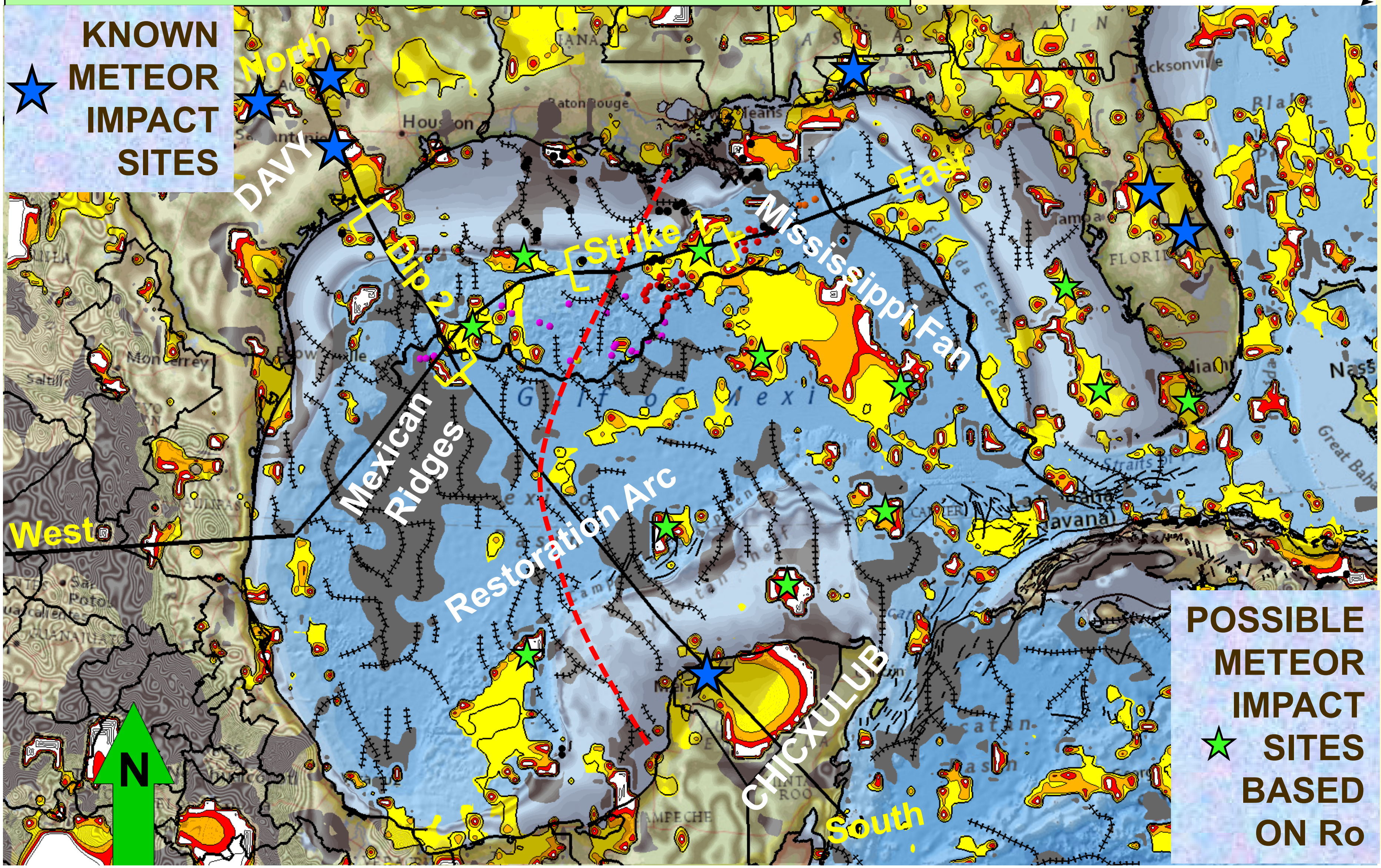


BSMENT HIGHS & PLANAR FACIES

Ro LESS THAN -3 & Ro >0

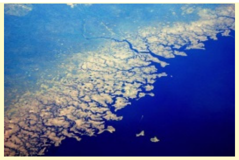
• 31 FIELDS with Current Production > 100 MMBOE

BSMT RIDGES

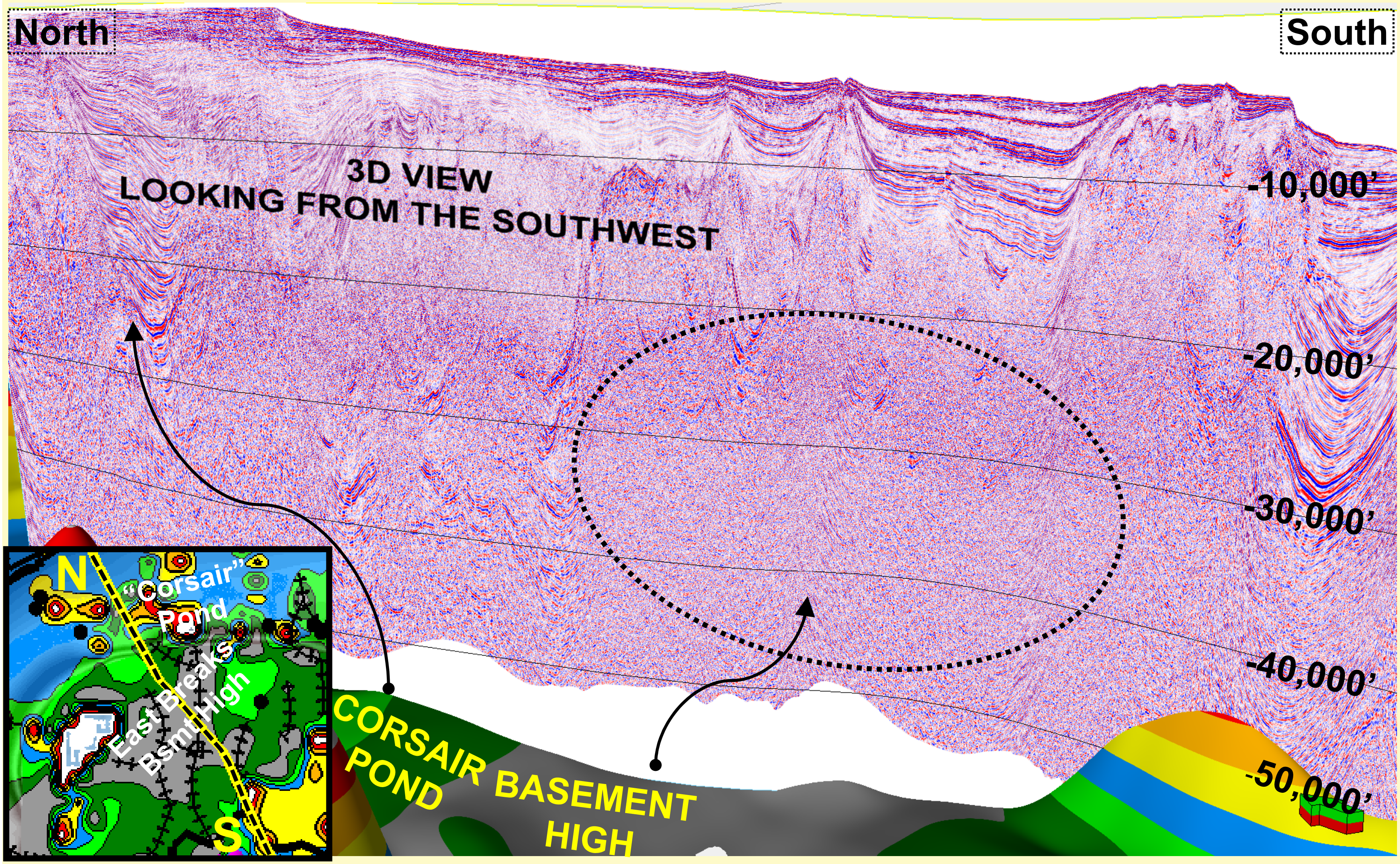


GULFSPAN 2D (PSDM) 2003/04 VINTAGE

DIP 2



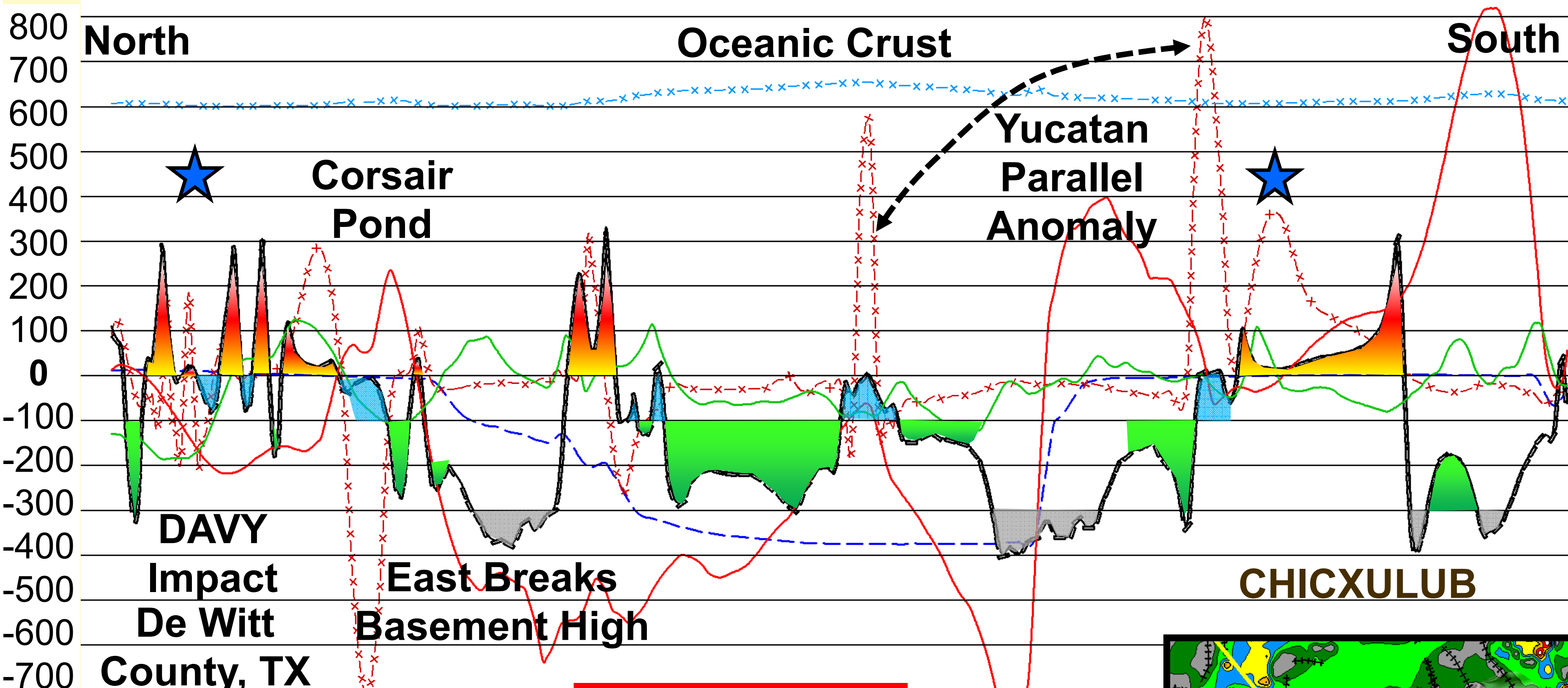
Courtesy of ION Geophysical

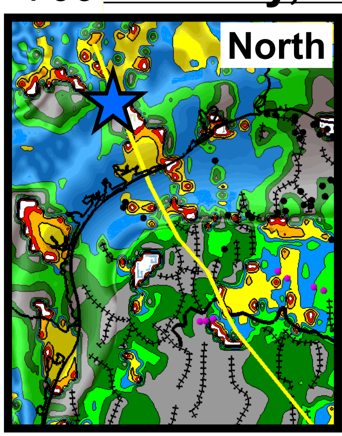


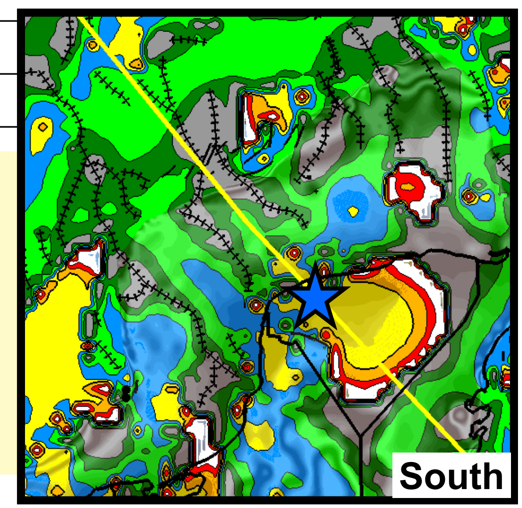
Ro SCALED FOR SEISMIC **Vertical Exaggeration ~ 7.5 to 1**

VERTICAL INTERSECTION

EXTENDED ALONG & BEYOND DIP2 LINE

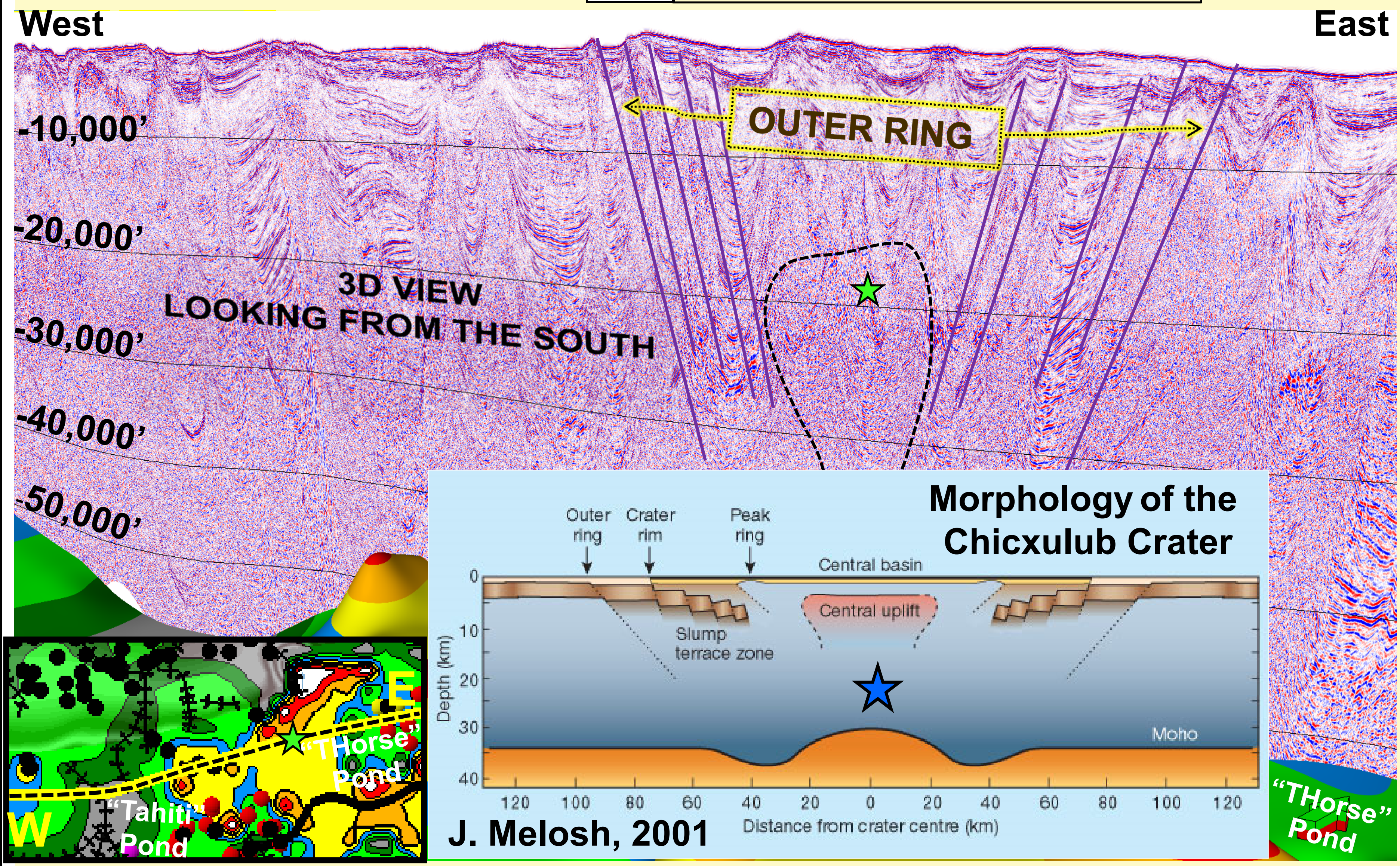






GULFSPAN 2D (PSDM) 2003/04 VINTAGE
STRIKE 1

Courtesy of ION Geophysical

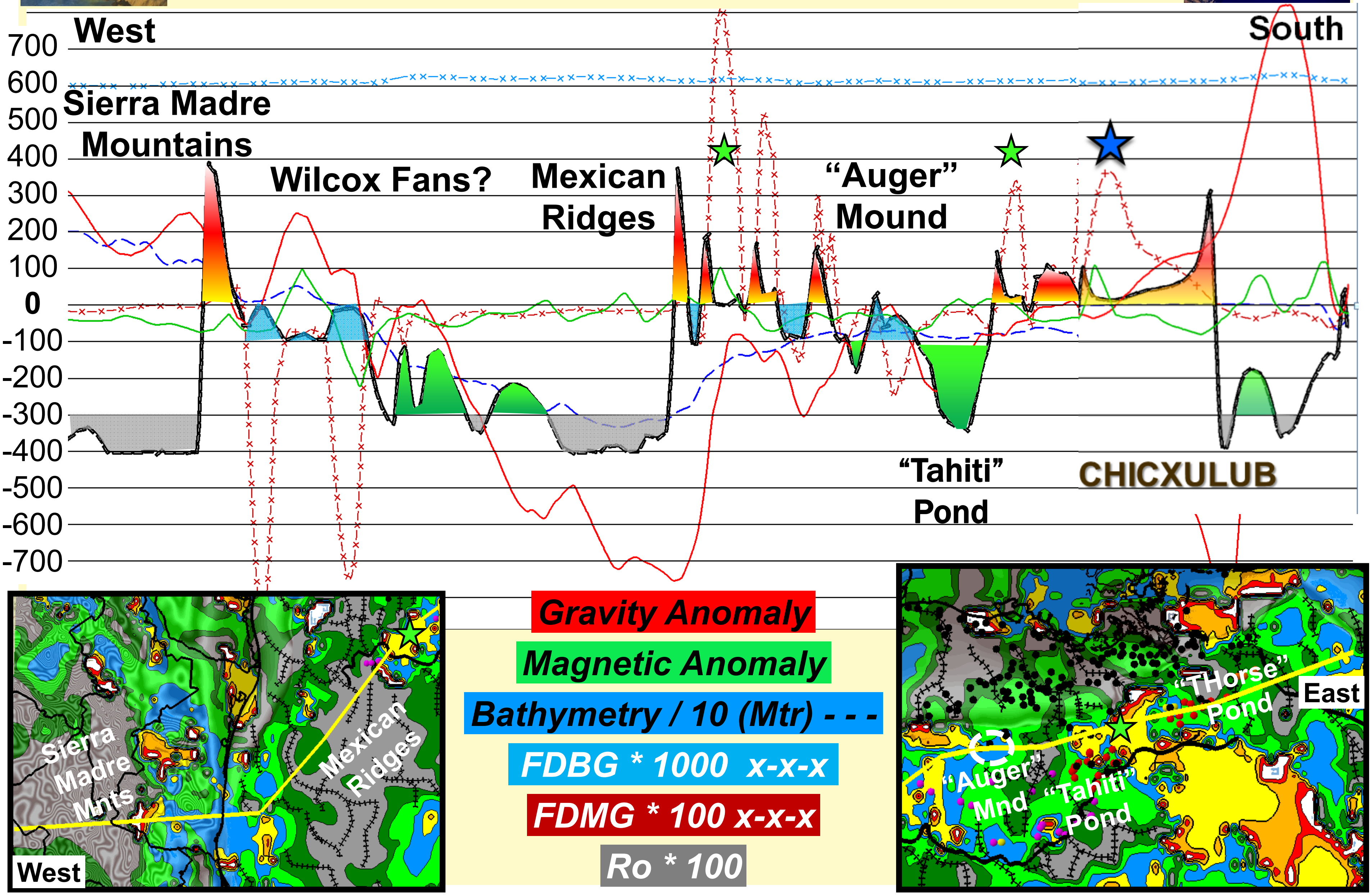


Ro SCALED FOR SEISMIC

Vertical Exaggeration ~ 7.5 to 1

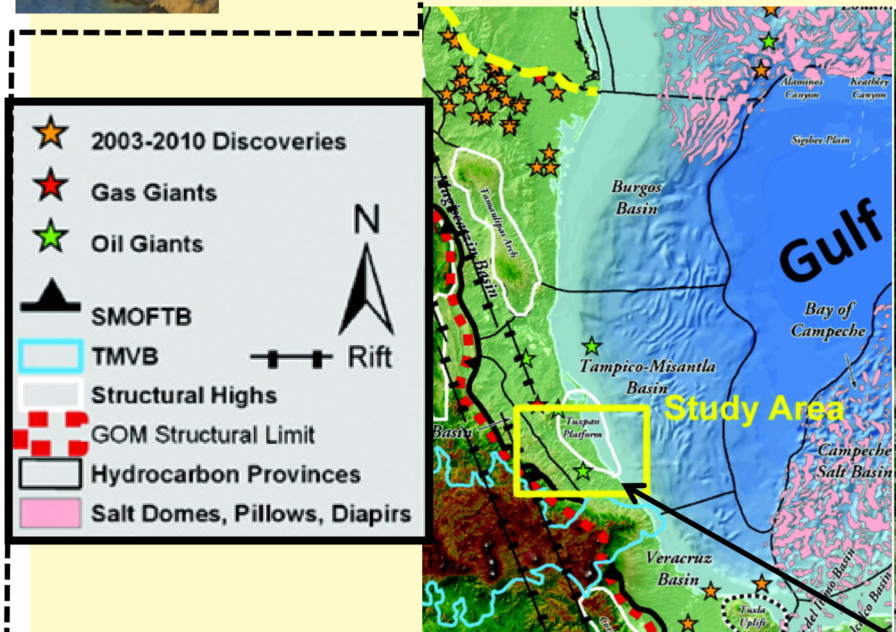
VERTICAL INTERSECTION

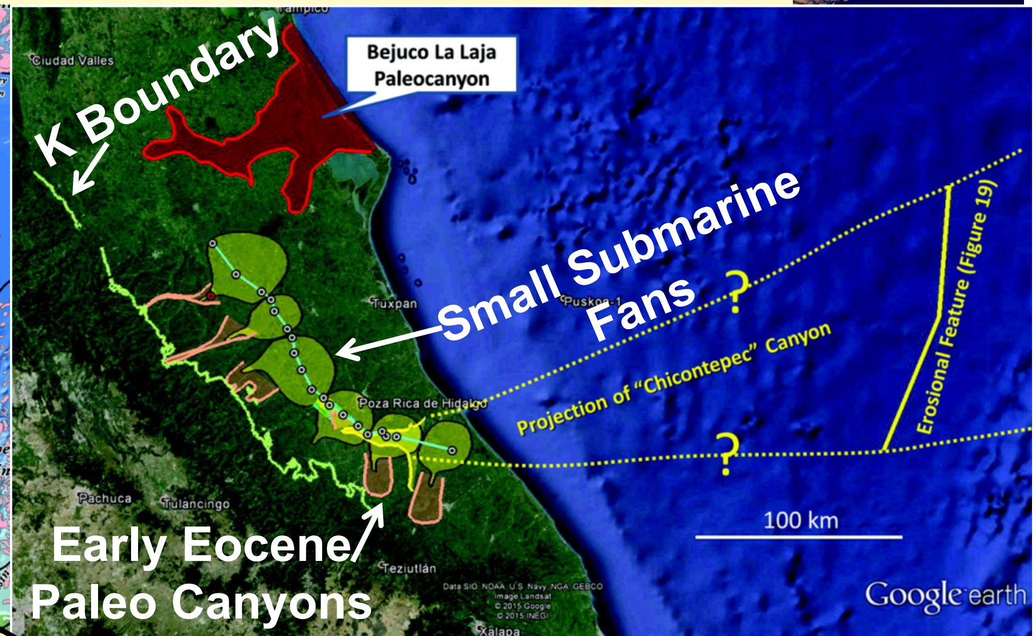
EXTENDED ALONG & BEYOND STRIKE1 LINE



WILCOX PALEOCANYONS IN EASTERN MEXICO

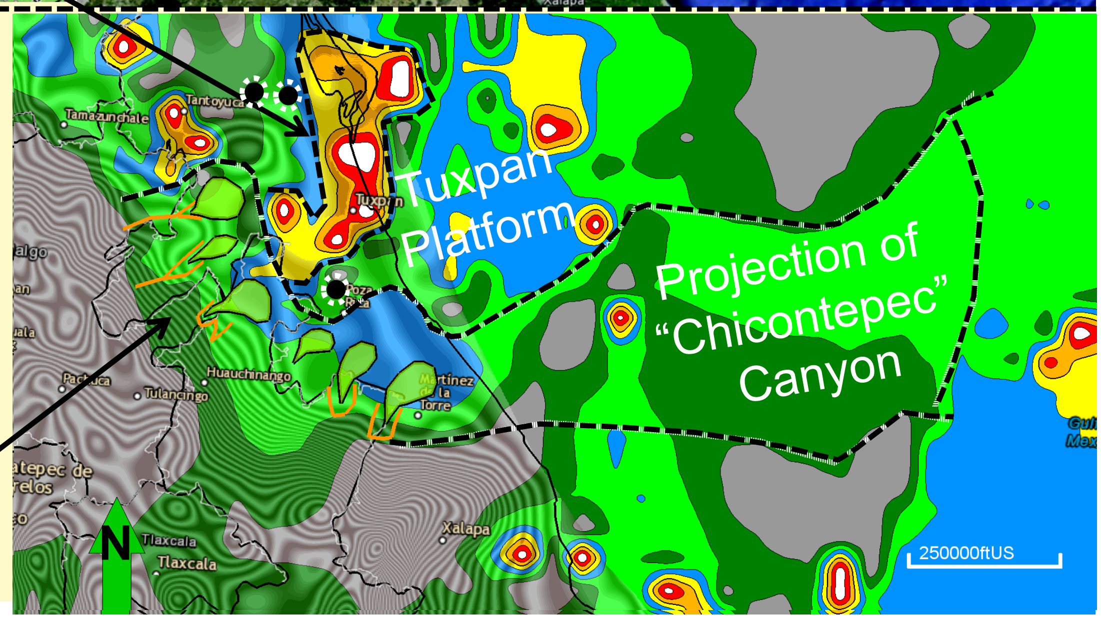
SEG INTERPRETATION/FEBRUARY 2016





COMPELLING EVIDENCE FROM EASTERN MEXICO FOR A LATE PALEOCENE /EARLY EOCENE ISOLATION, DRAWDOWN, AND REFILL OF THE GoM

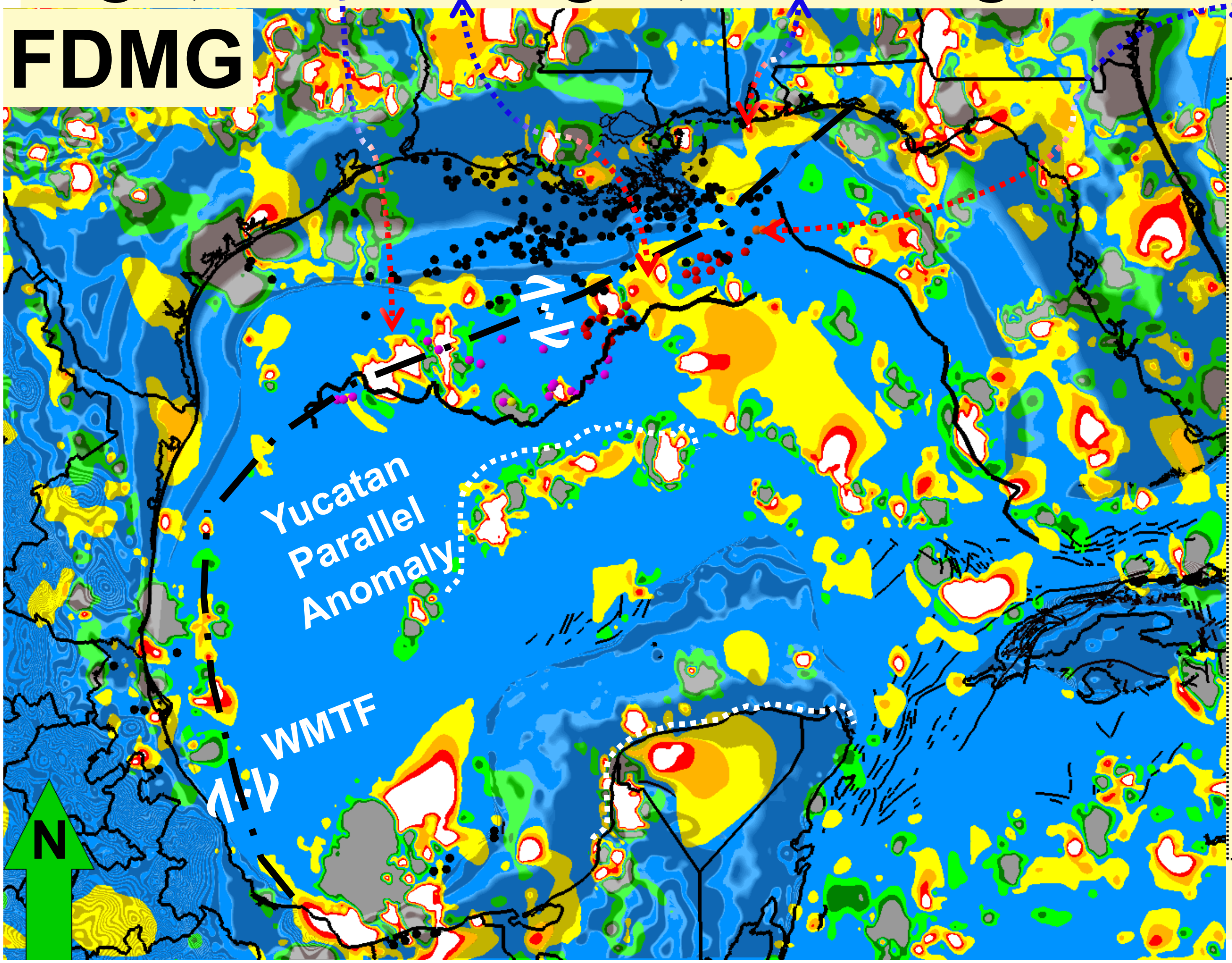
S. COSSEY ET AL.



Area of Wilcox Paleo Canyons and Submarine Fans on Ro

WESTERN MAIN TRANSFORM FAULT (WMTF)
SEG INTERPRETATION/FEBRUARY 2016

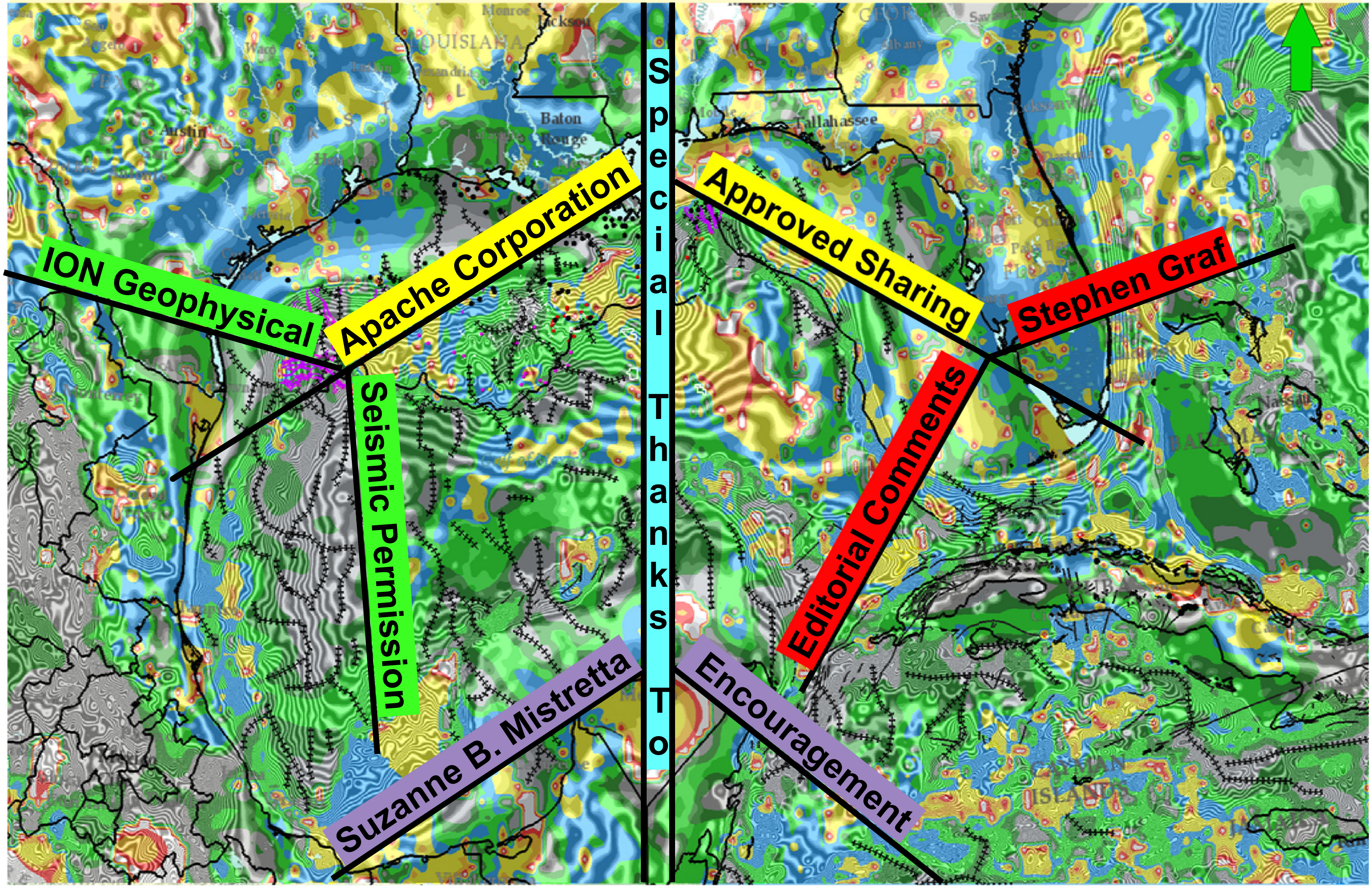
"Norton" Jurassic @ ~9,000' "Swan Valley" Jurassic @ ~12,000' "Mary Ann Field" Jurassic @ ~21,000' "Appomatox Field" Jurassic @ ~24,000'



Gravity and Magnetic constraints on the Jurassic opening of the oceanic GoM and the location and tectonic history of the Western Main Transform Fault along the eastern continental margin of Mexico

Nguyen & Mann

ACKNOWLEDGMENTS



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