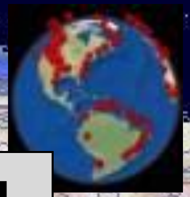


Two decades (2000-2020) and 5 paradigm shifts gleaned from AAPG's Giant Fields Database

October 22, 2021

Finding Petroleum: Super Basins 2: Giant Fields of the World

John C. Dolson[1]

Zhiyong He[2]

Brian W. Horn[3]

[1]DSP Geosciences and Delonex Energy

[2]Zetaware, Inc.

[3] Cairn Energy India

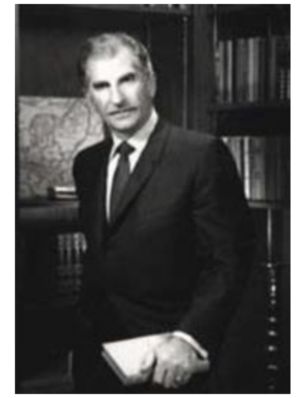
But First: a Word on the Updated AAPG Giant Fields GIS Database

John C. Dolson

DSP Geosciences and Associates
Coconut Grove, Florida

Giant fields history—thousands of contributors

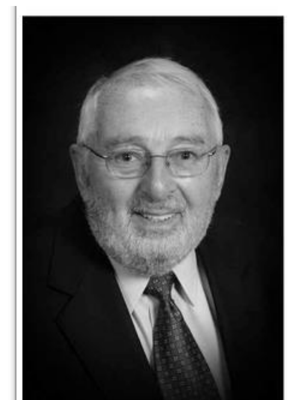
- 60% of world reserves!
- Extending a 50 year history of AAPG Giant Field documentation
  - a treasure-trove of collective knowledge
- First digital rollout in GIS format: 2003, Myron K. Horn
  - Last update 2010
    - Myron Horn passed away 2016
- This version
  - 5 year effort starting in 2016 by John Dolson
    - Preparation for 2017 Middle Workshop on Stratigraphic traps



Michel Halbouty
(1909-2004):

"First, study the usual about accumulations"

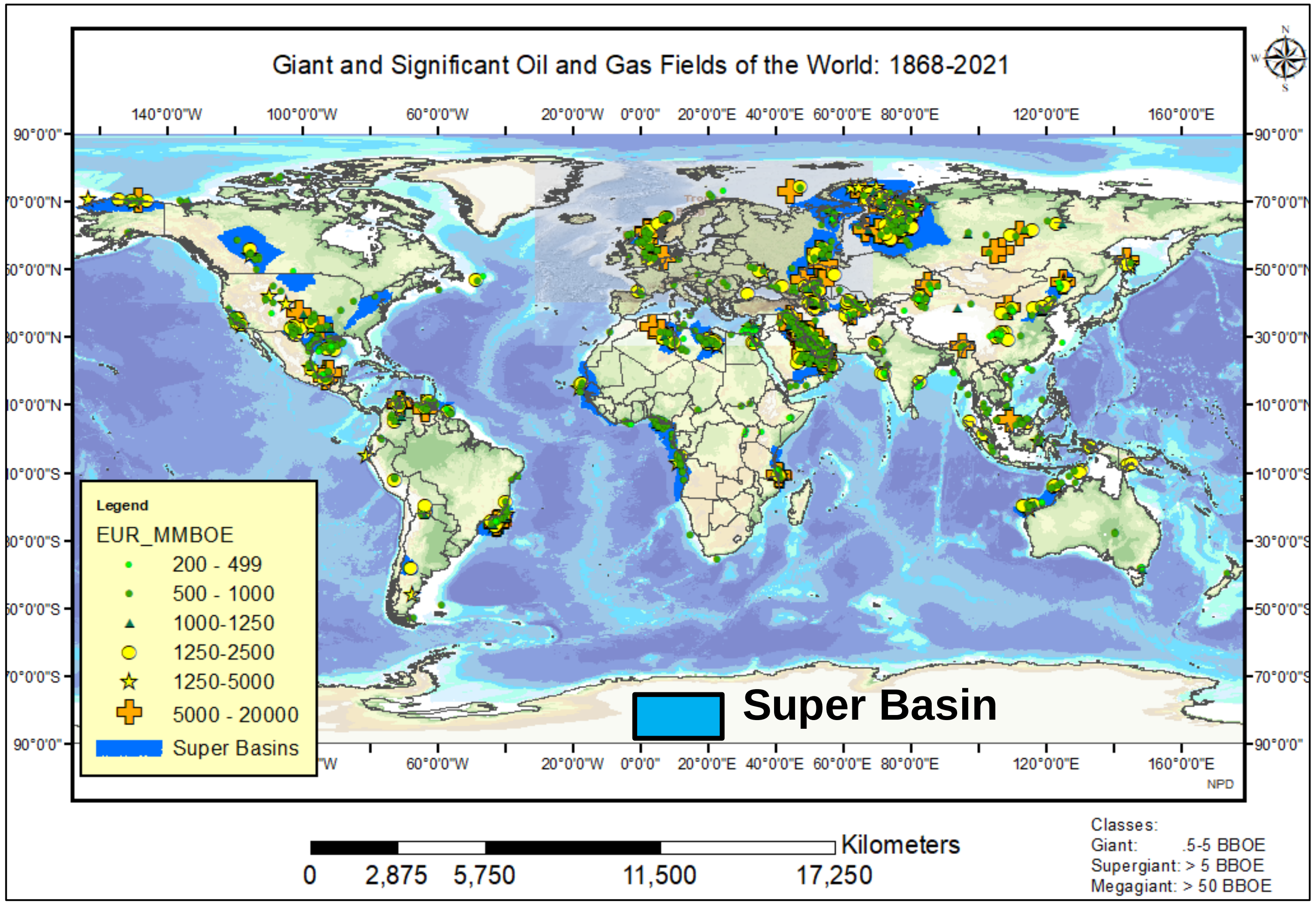
"Then, concentrate on the unusual—that is often where the future lies"



Myron K. Horn
(1930-2016)

Robert Merrill
Charles Sternbach
(2 Giant Field Memoirs covering the last 20 years

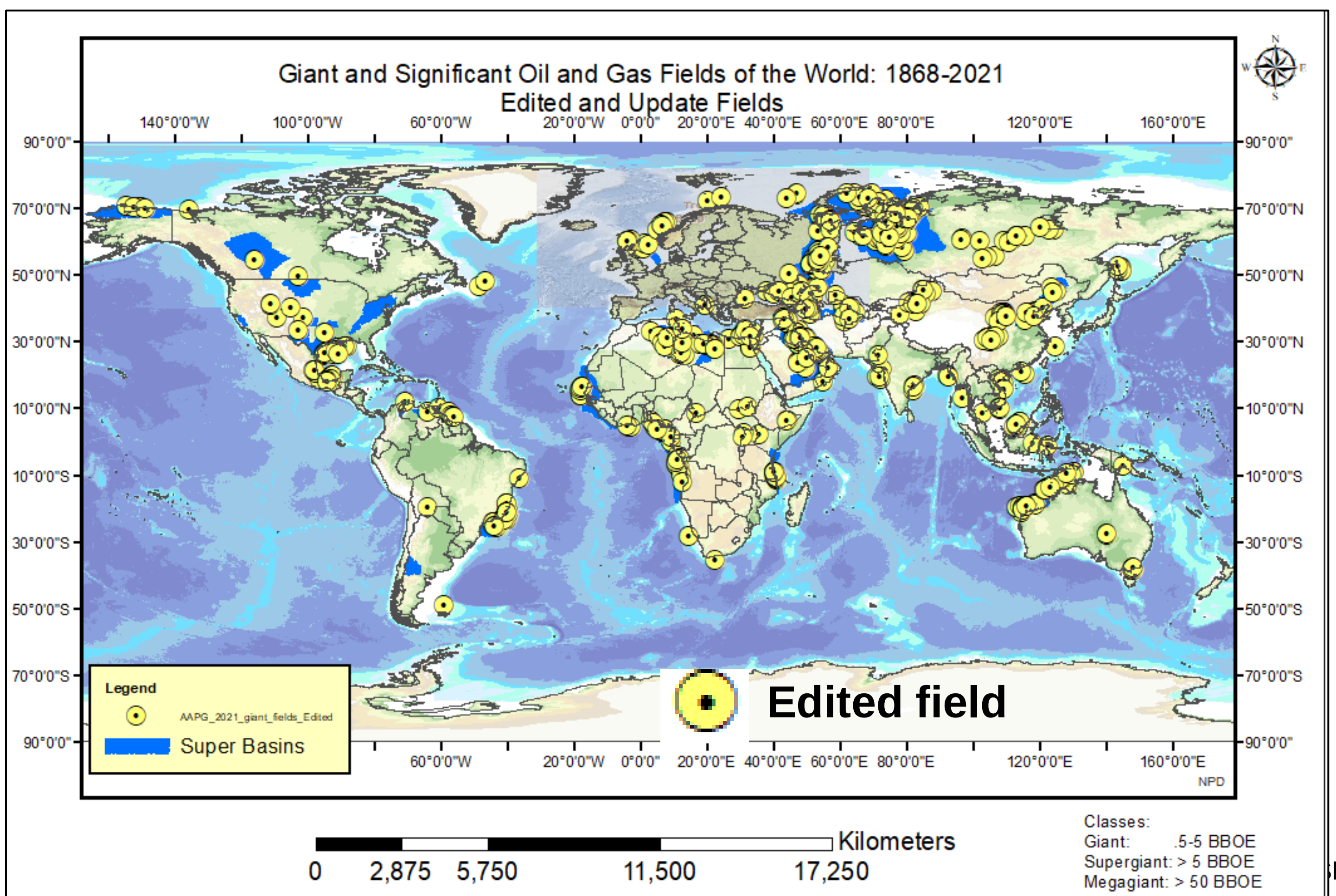
J. Dolson
Co-editor, contributor,
2021 Giants of the Decade 2010-2020
(Standing on the shoulders of giants)



1204 Giant and Significant Fields

4900 + references searchable by field name

<u>Keys to understanding Super Basins and Evolving plays</u>



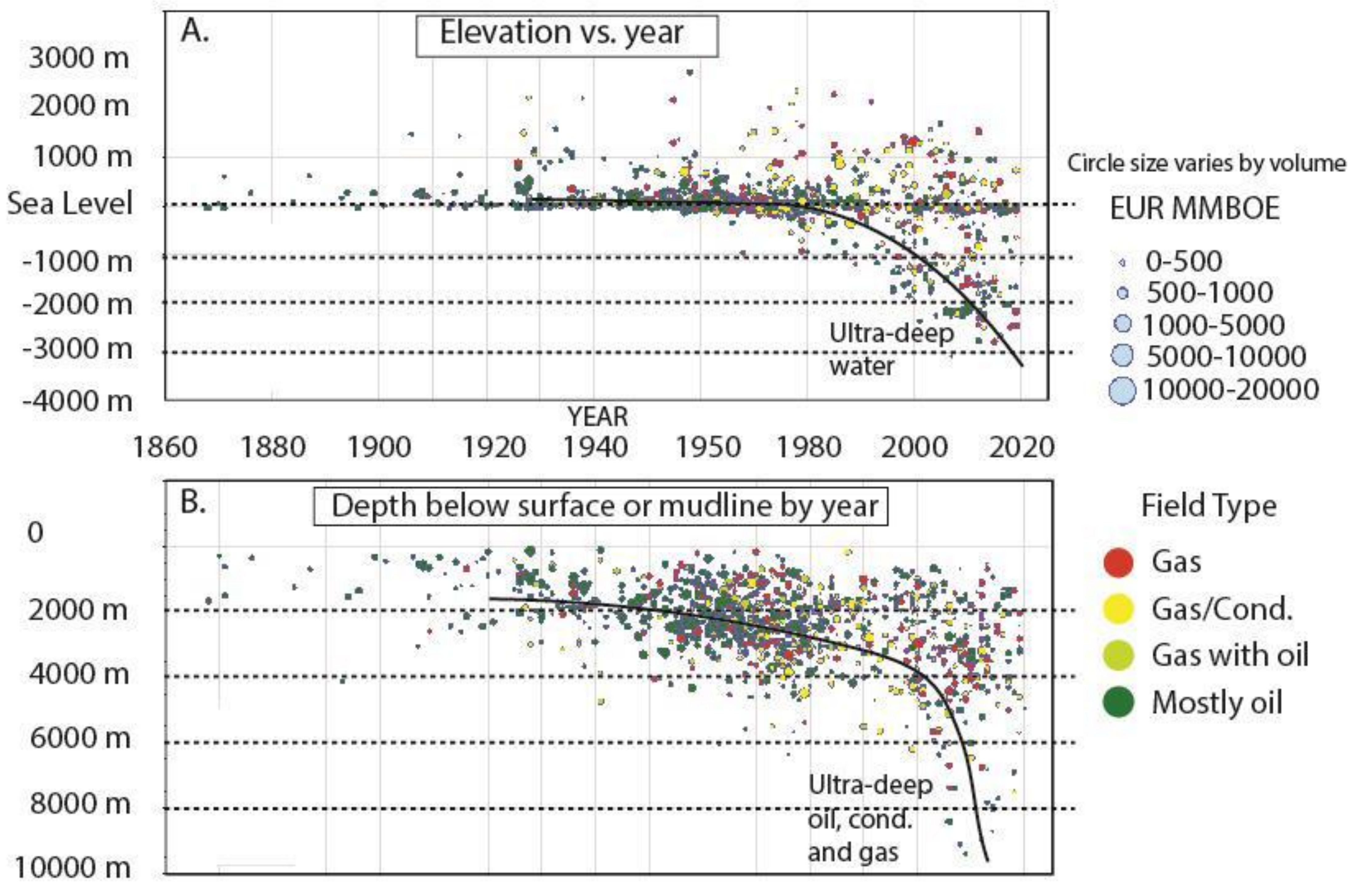
hifts

646 Fields edited or added 1000+ new references

New data:

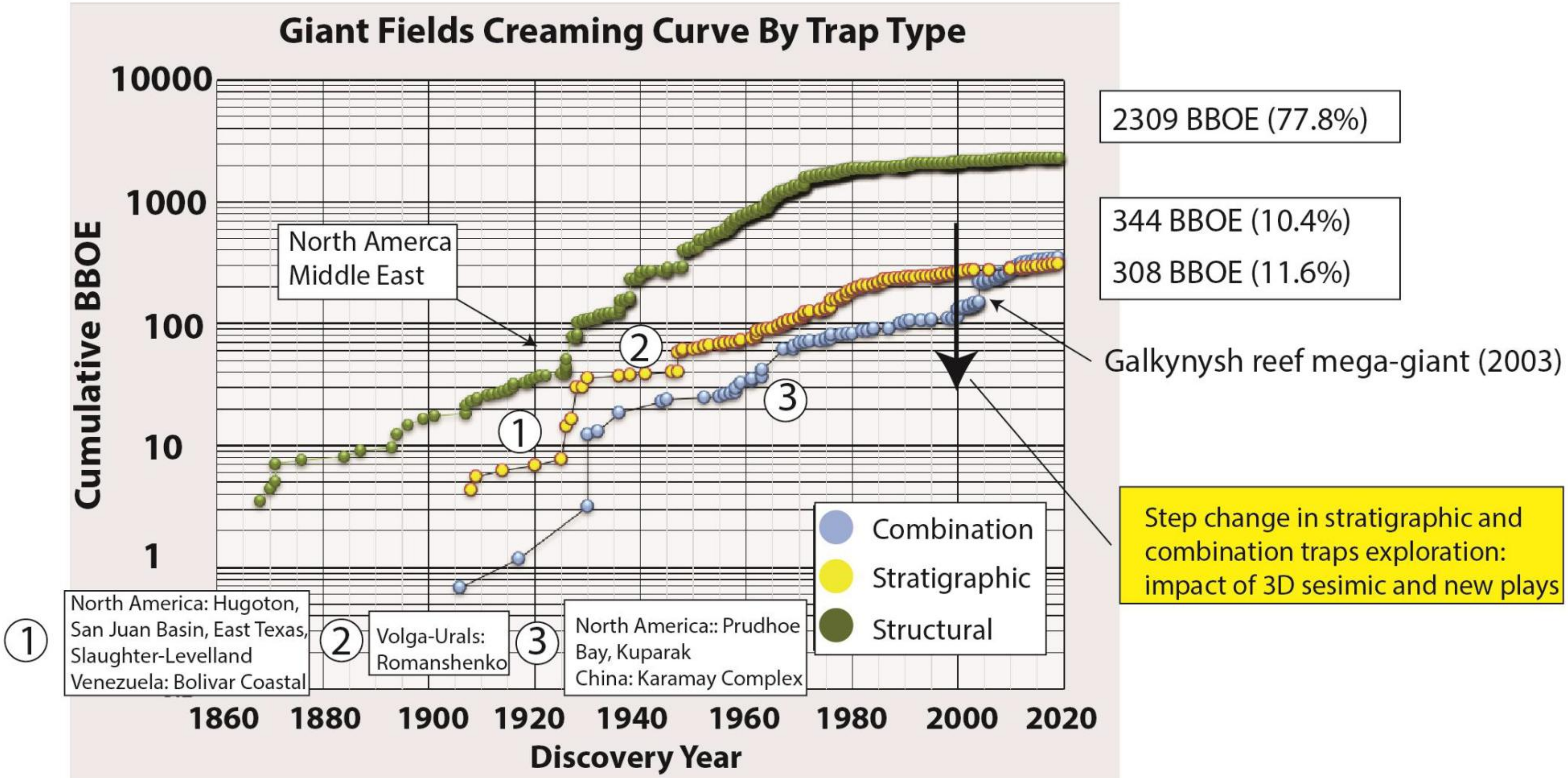
- **Elevation**
- **Depth below mudline**
- **Operator**

First: Deeper water, deeper below mudline and deeper stratigraphy!—still oil!

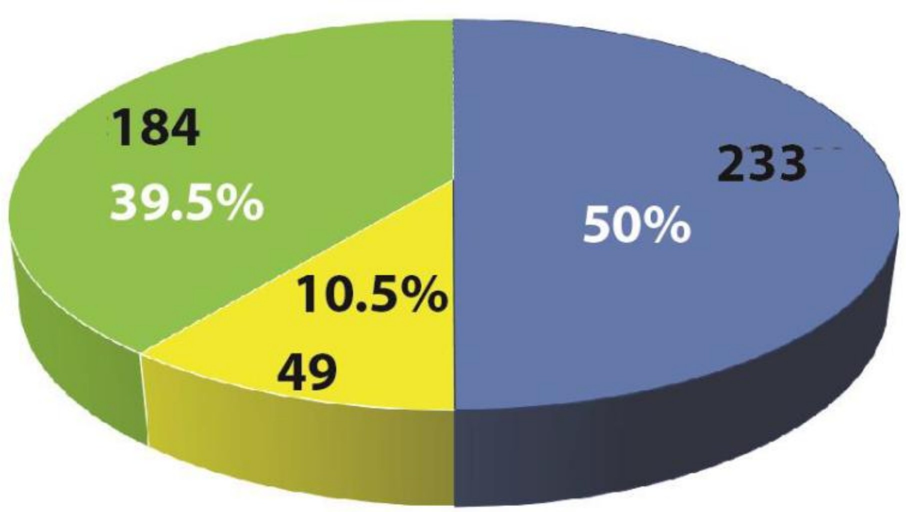


Last 20 years paradigm shifts

- Stratigraphic/Combination traps now 50% of giants, vs. historical 10%
  - 3D seismic reservoir imaging and integration is key
- Explosion of unconventional exploration
- Giants over oceanic crust
- Giants with oil and liquids at great depth
  - 7-10 Km below mudline
  - Good reservoir, high pressure
  - Tapping the oldest, deepest petroleum systems
- Hydrodynamic upward flow in over-pressured basins
  - Under-appreciated and tilted contacts

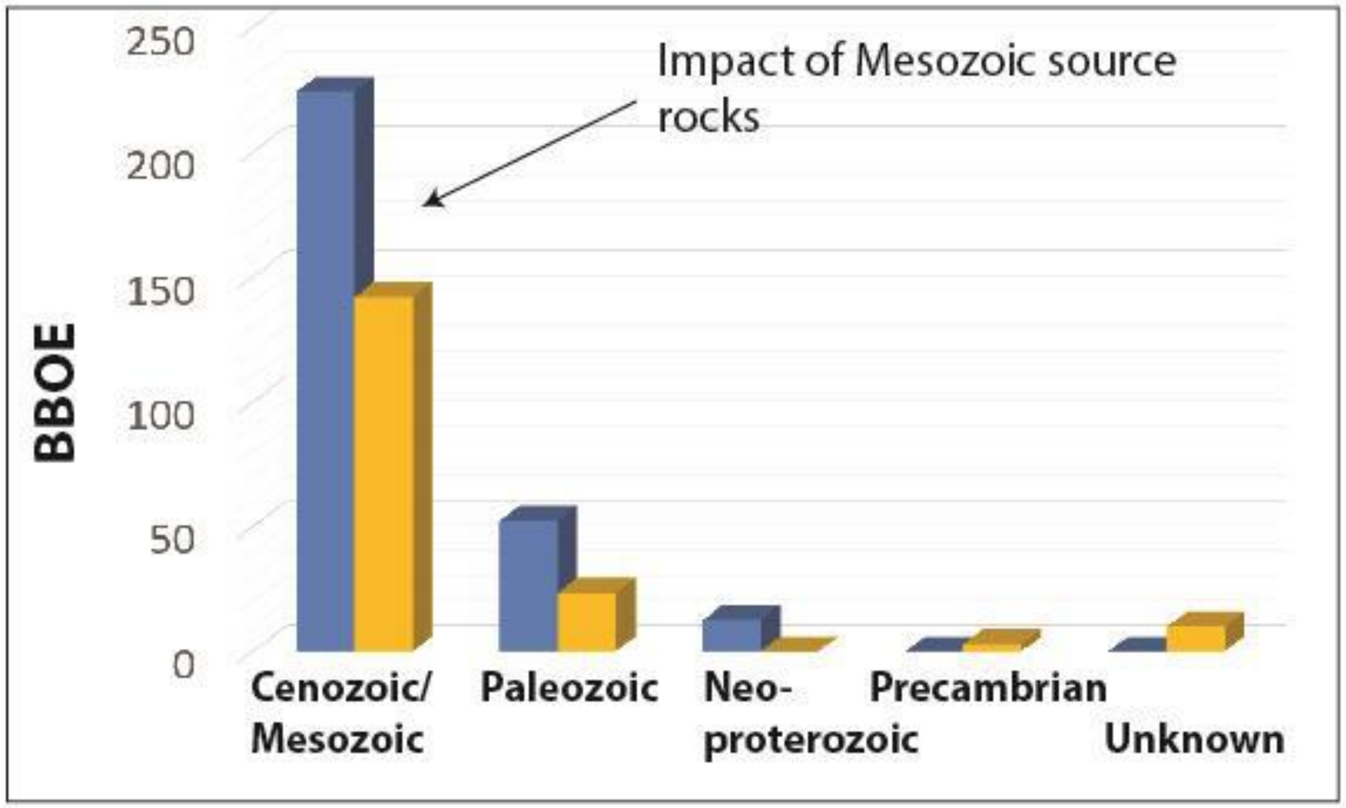


Giant Fields Discovered Since 2000 by Trap Type: BBOE



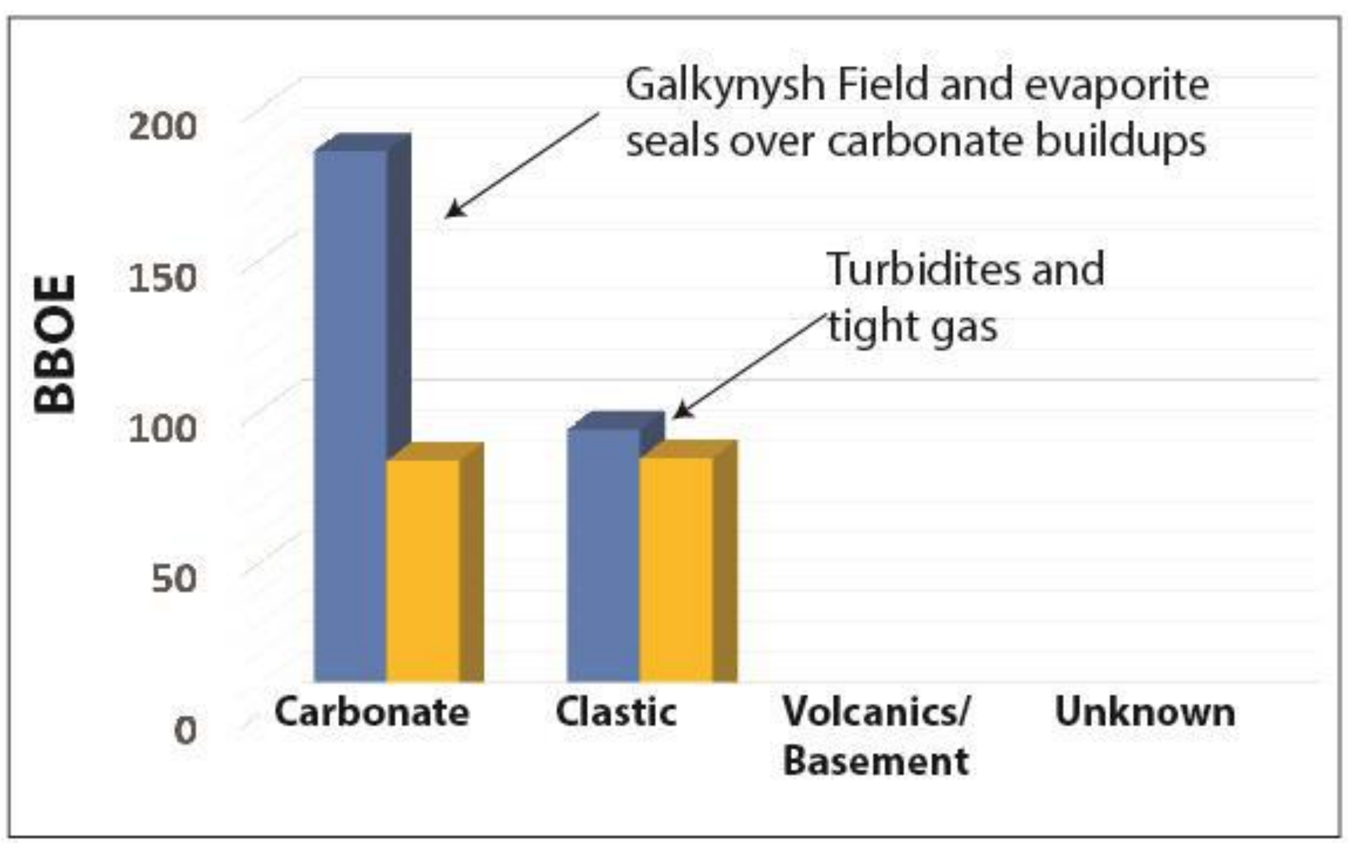
Since 2000, 60% of the giant field reserves found have been combination and stratigraphic traps

A. Giant Fields Found Since 2000 by Age and Trap Type



Source rock driven volumes

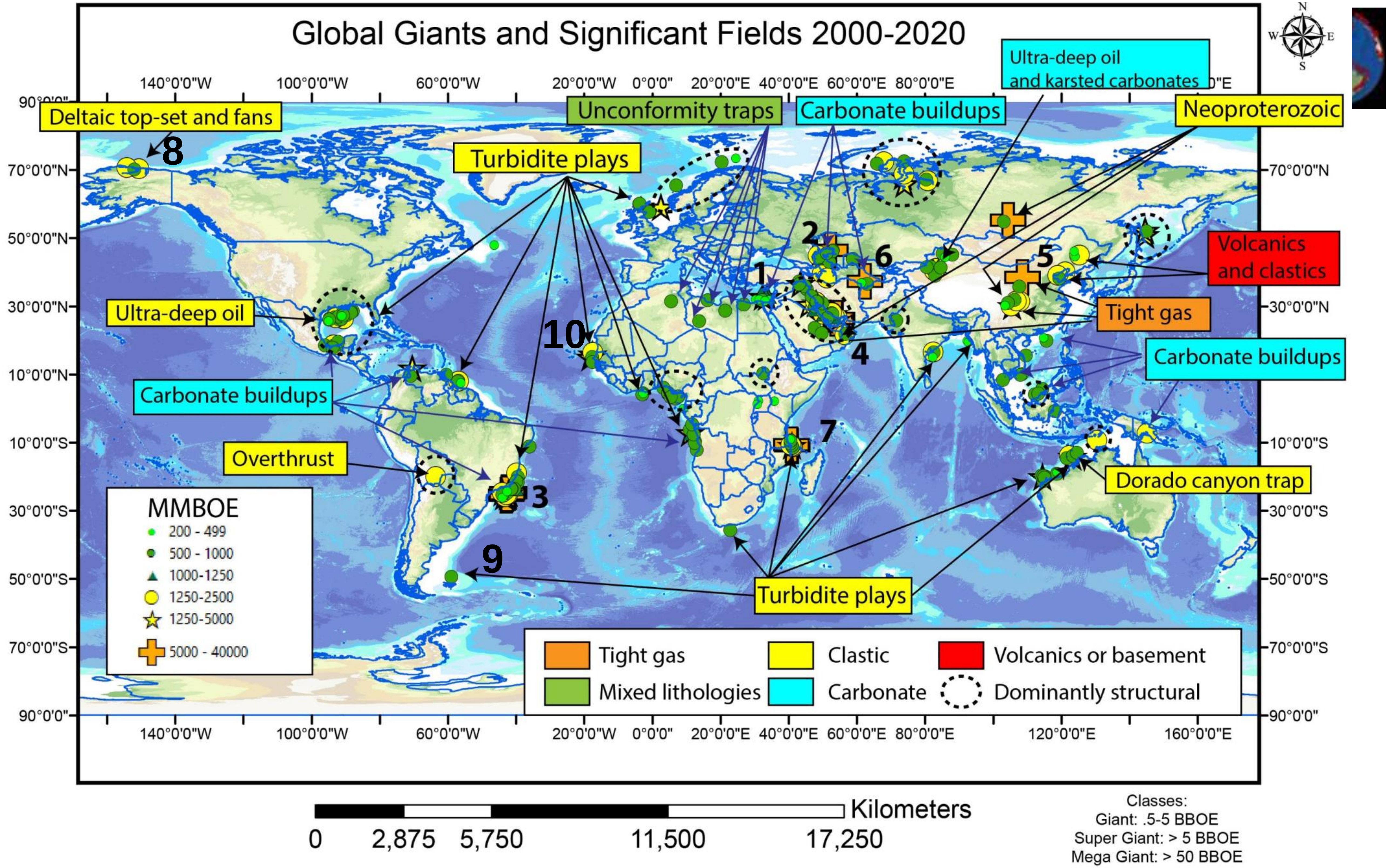
B. Giant Fields Found Since 2000 by Lithology and Trap Type



Trap Type

- Combination/ Stratigraphic
- Structural

Facies driven volumes



Highlighted field numbers: 1) Zohr reef, Egypt 2) Caspian Carboniferous reefs 3) Pre-salt carbonates, Brazil 4) Cambrian tight gas-Khazzan, Oman 5) Ordos Basin tight gas 6) Galkynysh mega-giant Jurassic reef 7) Tertiary-Cretaceous turbidite complexes, East Africa 8) Deltaic topset play, Alaska

Examples of 3D seismic facies imaging advances

A, B: Libra lacustrine carbonates, Santos Basin

A.

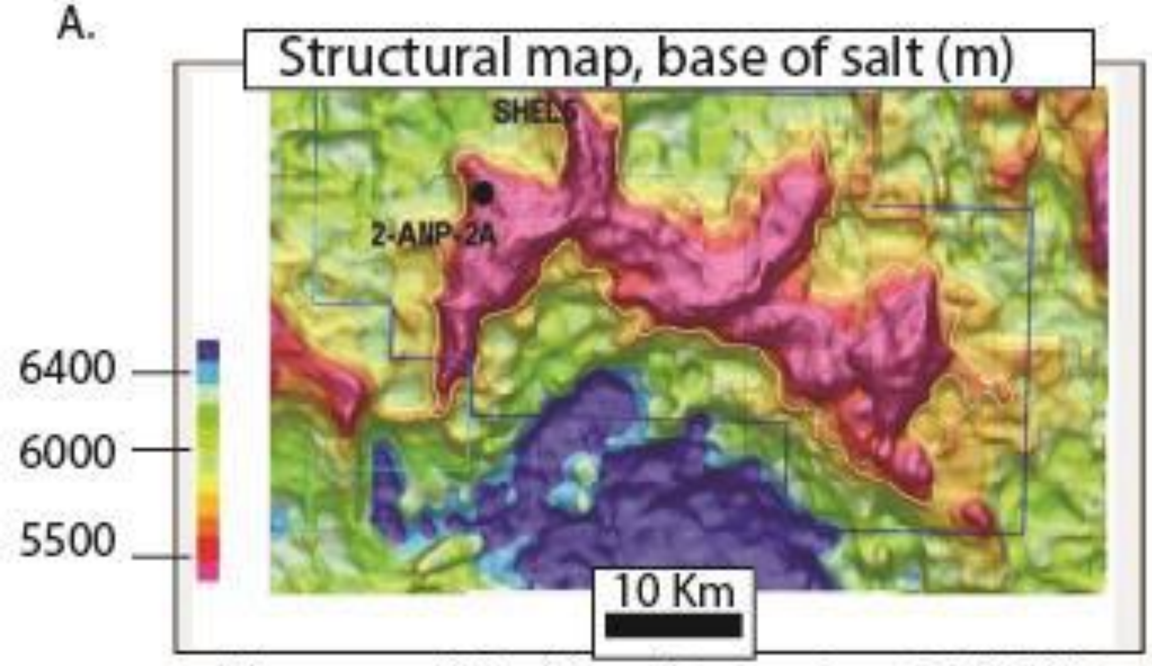
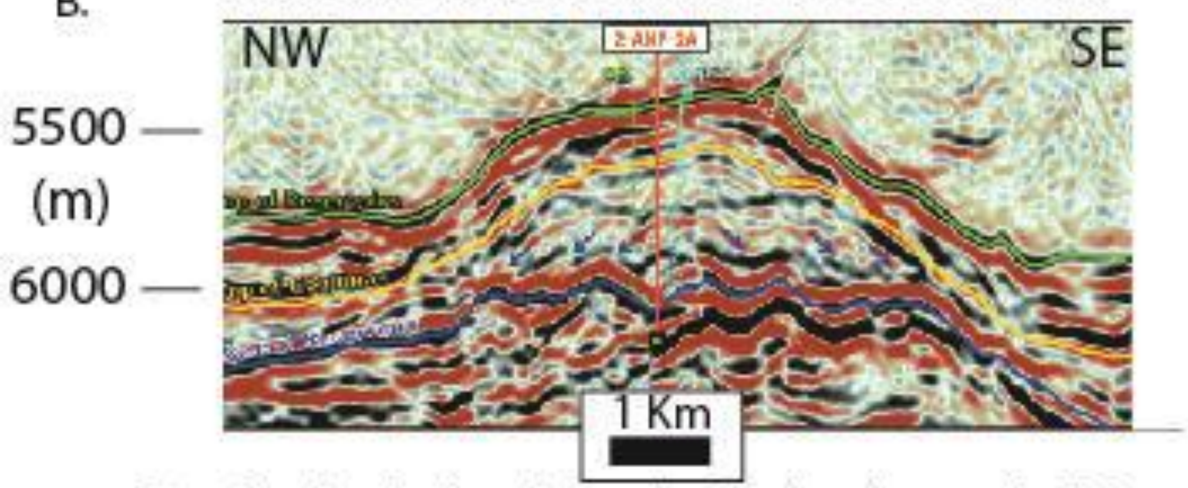


Figure modified from Rassenfoss, 2017, JPT

B.



Depth seismic showing microbial carbonate buildup
Modified from Carlotto et al., 2017, AAPG Memoir 113

C. Coral Field turbidite channel complex, Mozambique

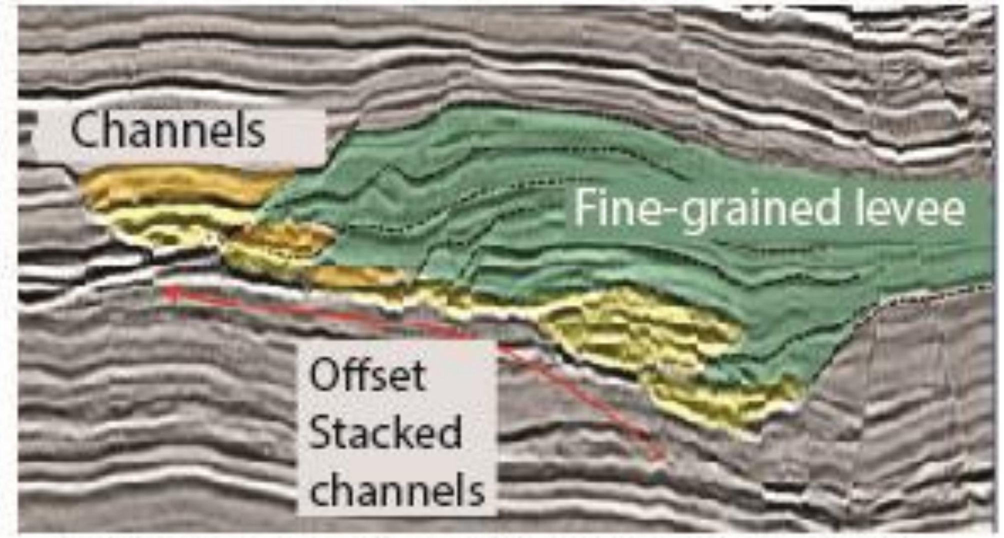


Figure modified from Palermo et. al., 2014

D. Eocene fluvial channel complex, Africa

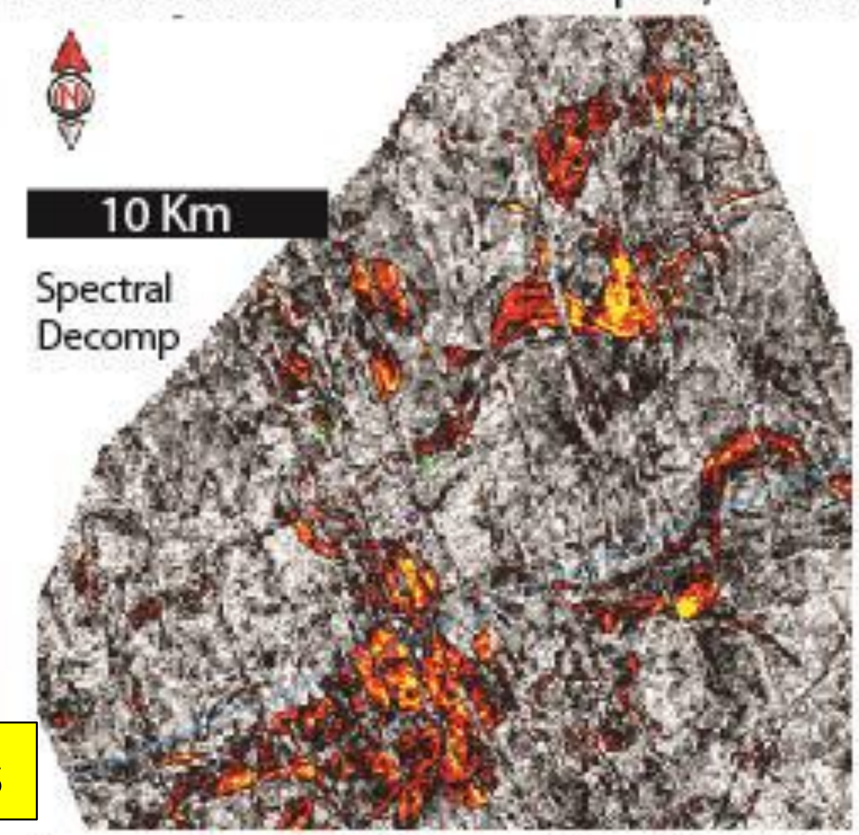
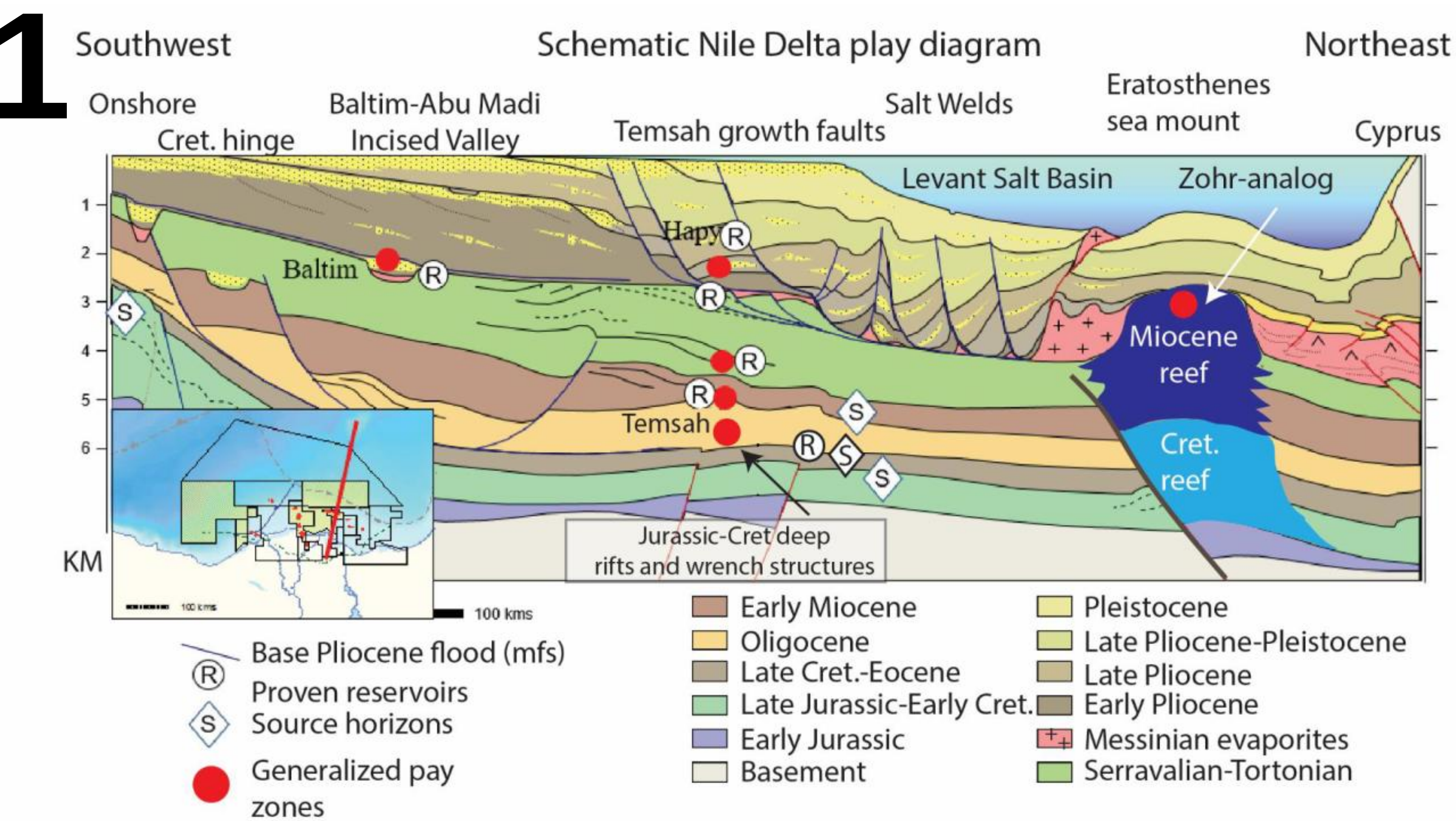
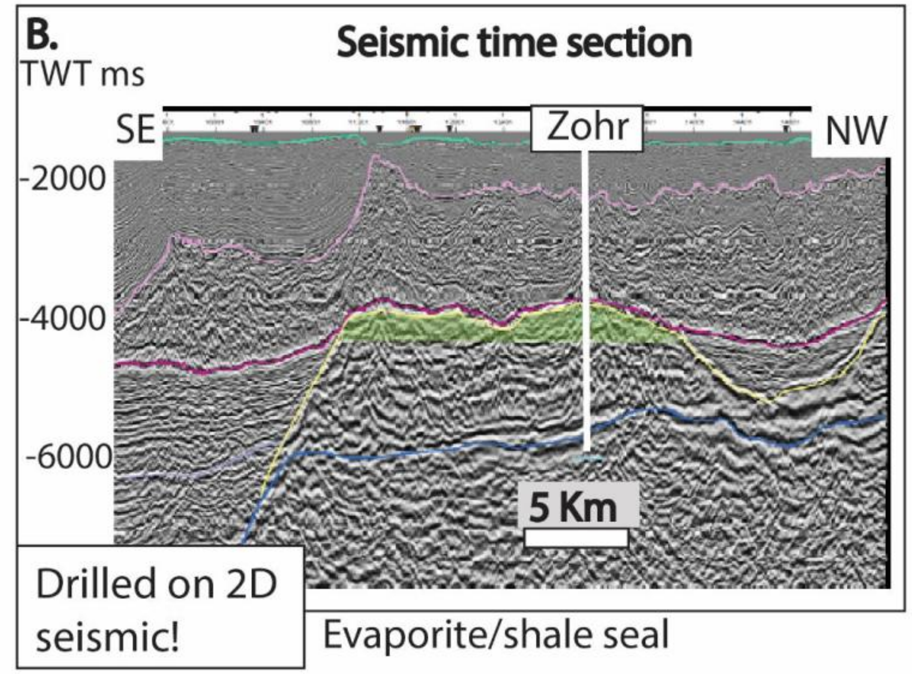
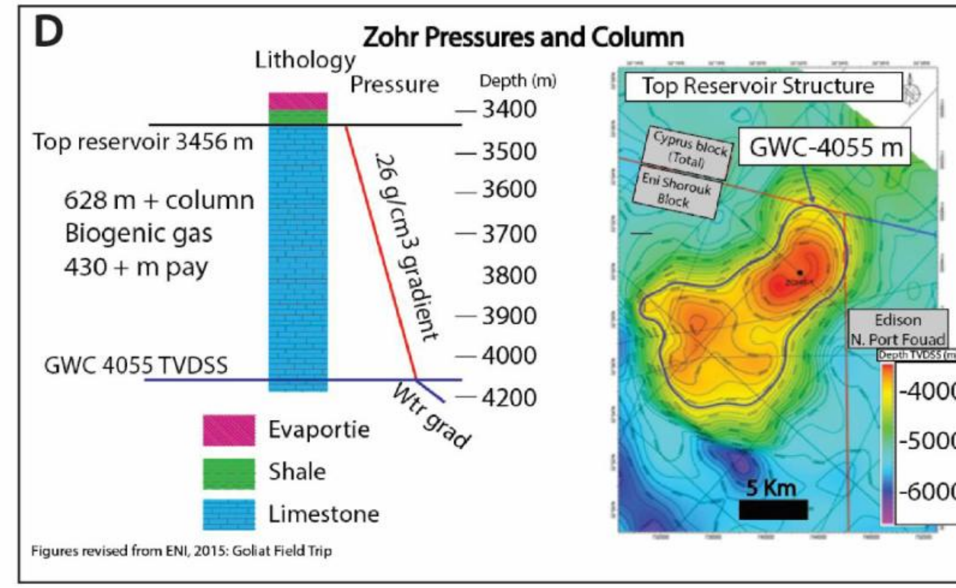


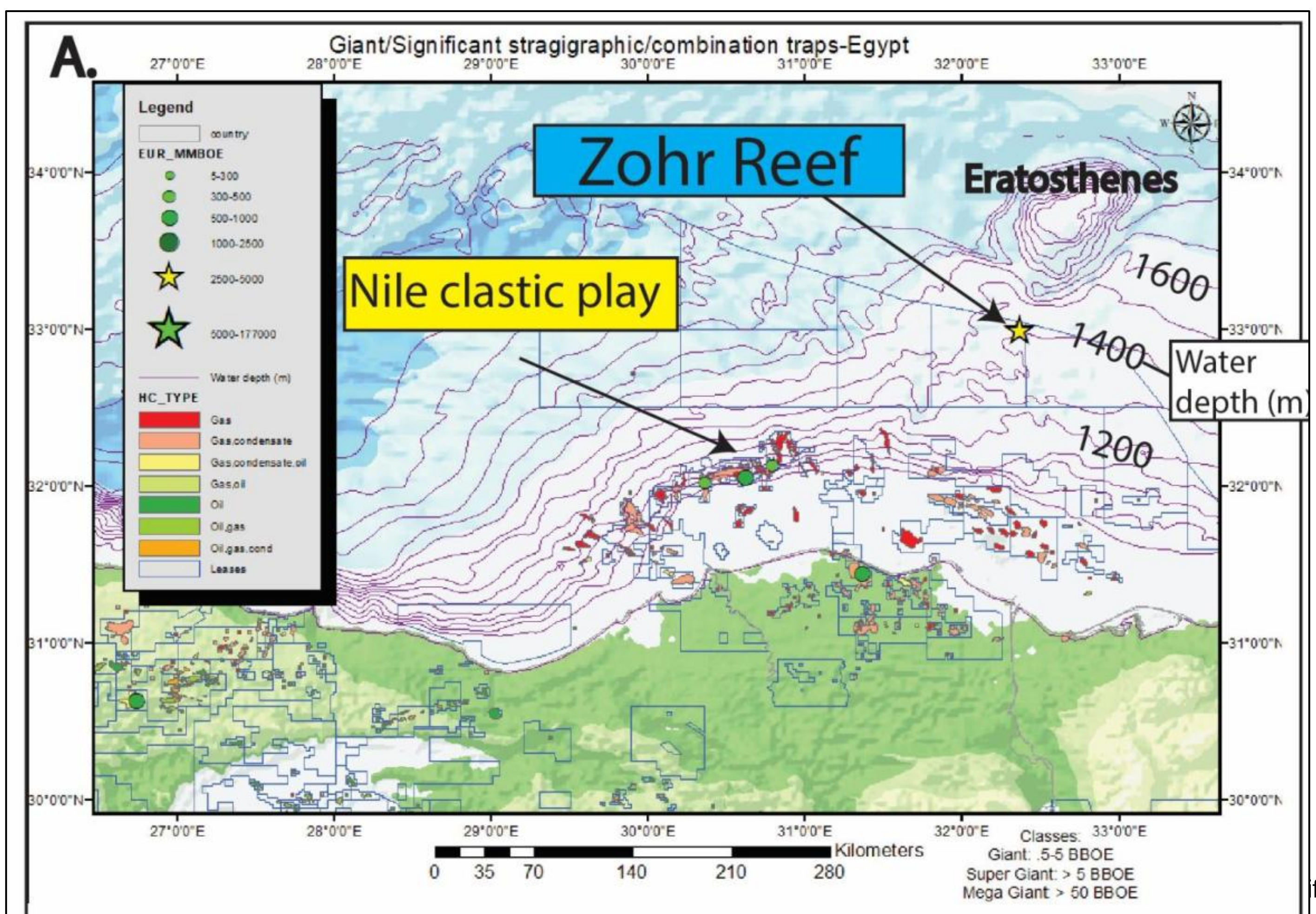
Image courtesy of UHCL, by permission of the Ministry of Petroleum and Energy of Chad

Breakthrough technology for stratigraphic traps



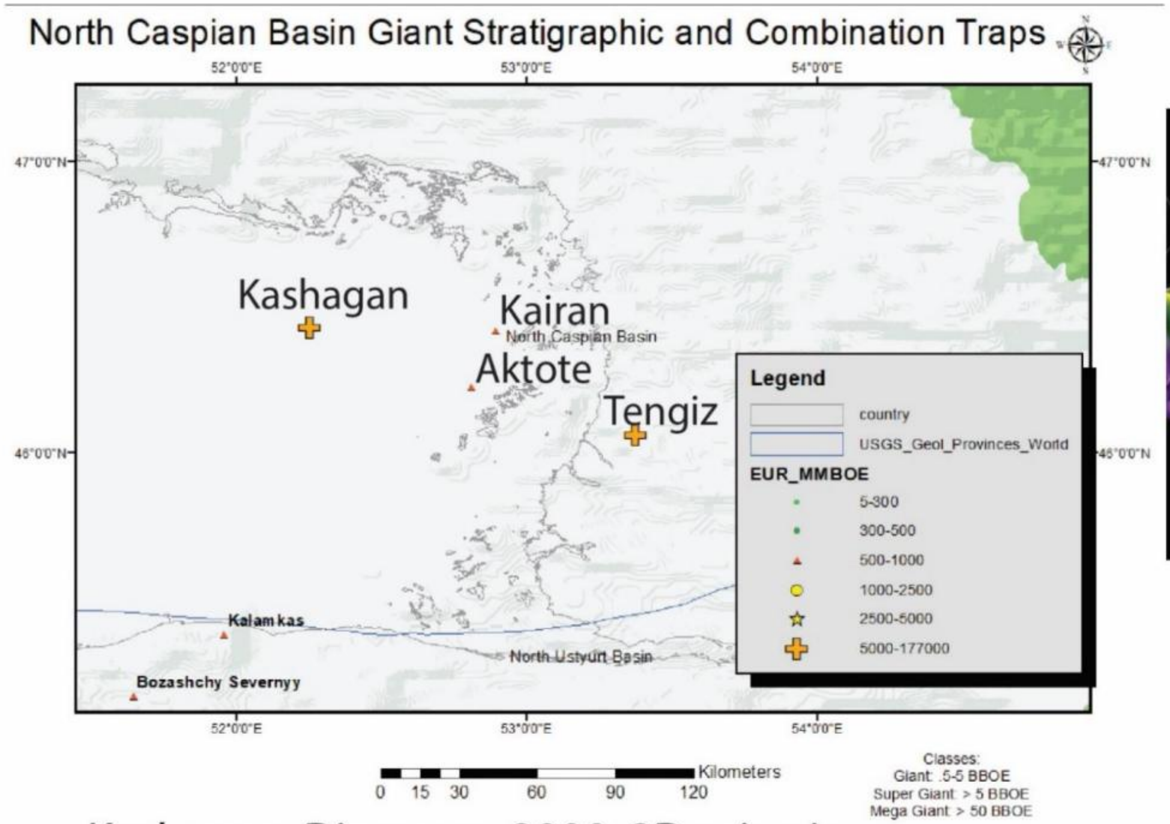




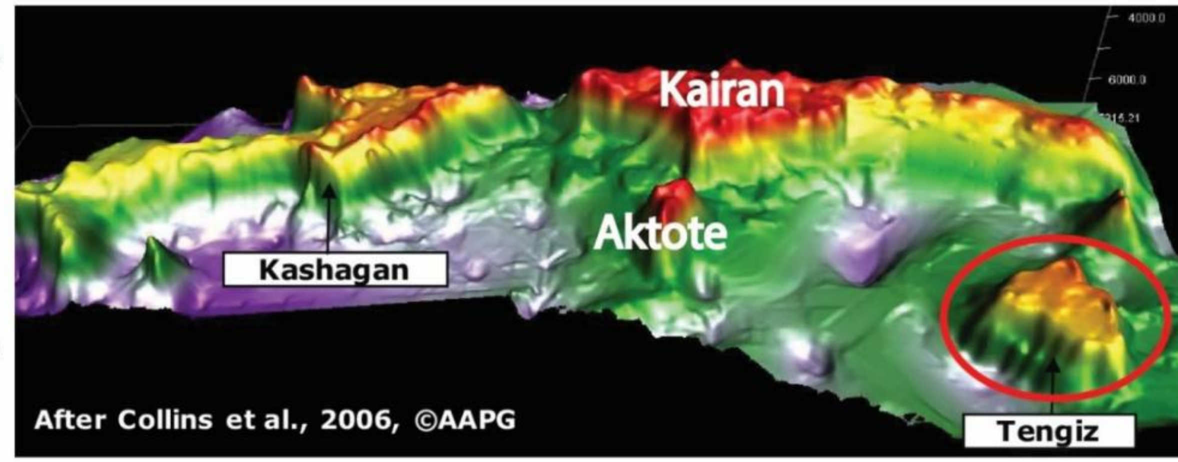


ifts

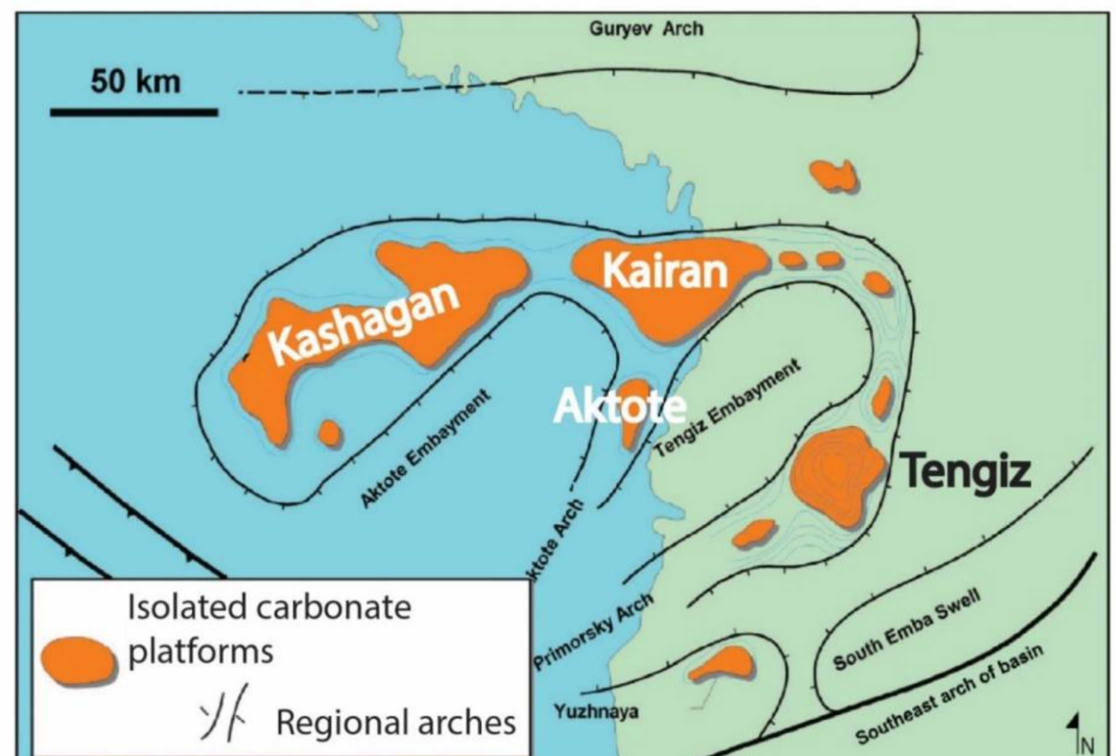
New play, old Basin: The Zohr Reef discovery, Egypt (ENI, 2015)



3D structural rendering of the Kashagan/Tengiz trend



Slide courtesy of Mitch Harris, Univ. of Miami lecture, 2017 (modified)



Modified from Kenter et al., 2006, AAPG Memoir 88

Kashagan: Discovery 2000, 2D seismic

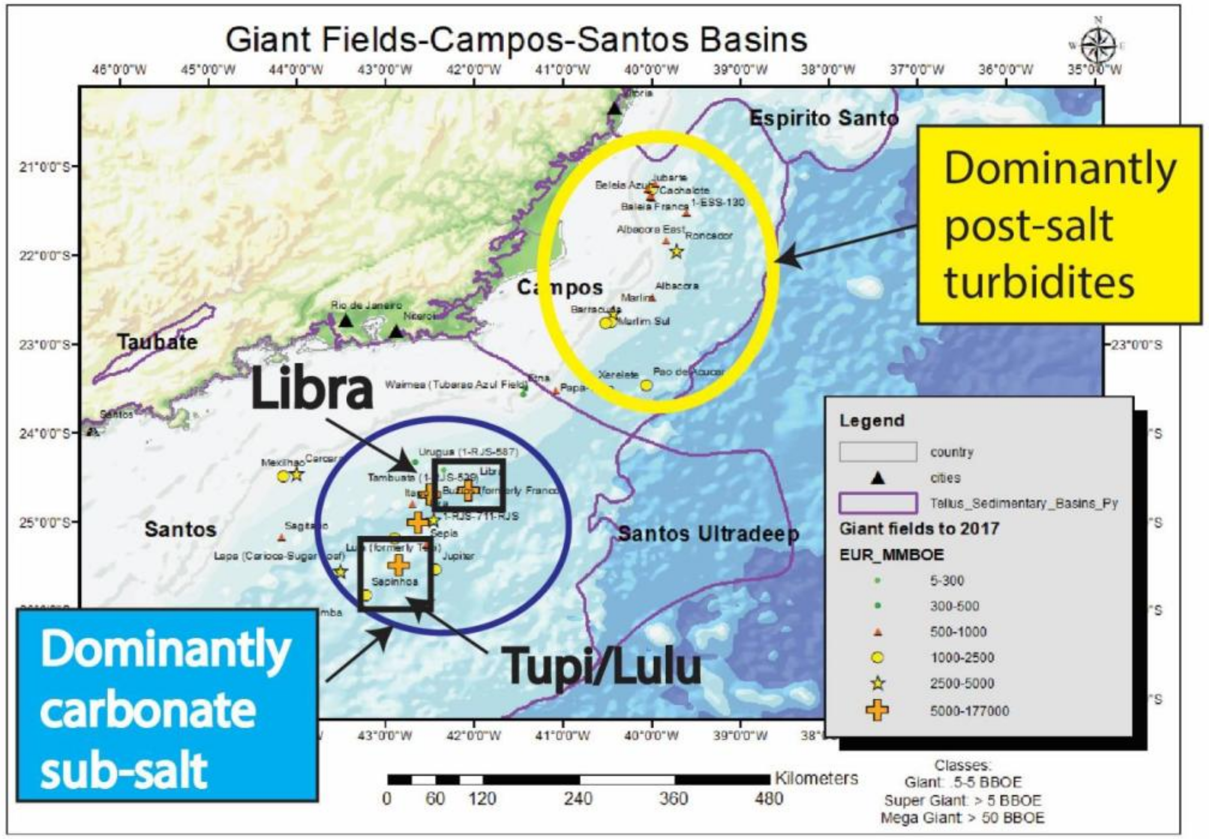
May exceed 28 BBOE;
10 BBO, 20 TCF (13.3 BBOE in this paper)

Carboniferous isolated platform

Salt sealed, high pressure
75 X 35 Km trap: 2625 Km^2
400 m column, 46 API, 16% H_2S

Aktote (2003)- 5.6 TCF with oil
Kairan (2003)- 740 MMBO
Tengiz (1980)- 5.8 BBO; 11.9 TCF

3 Pre-Salt Carbonates, Brazil



Structural map, base of salt (m)

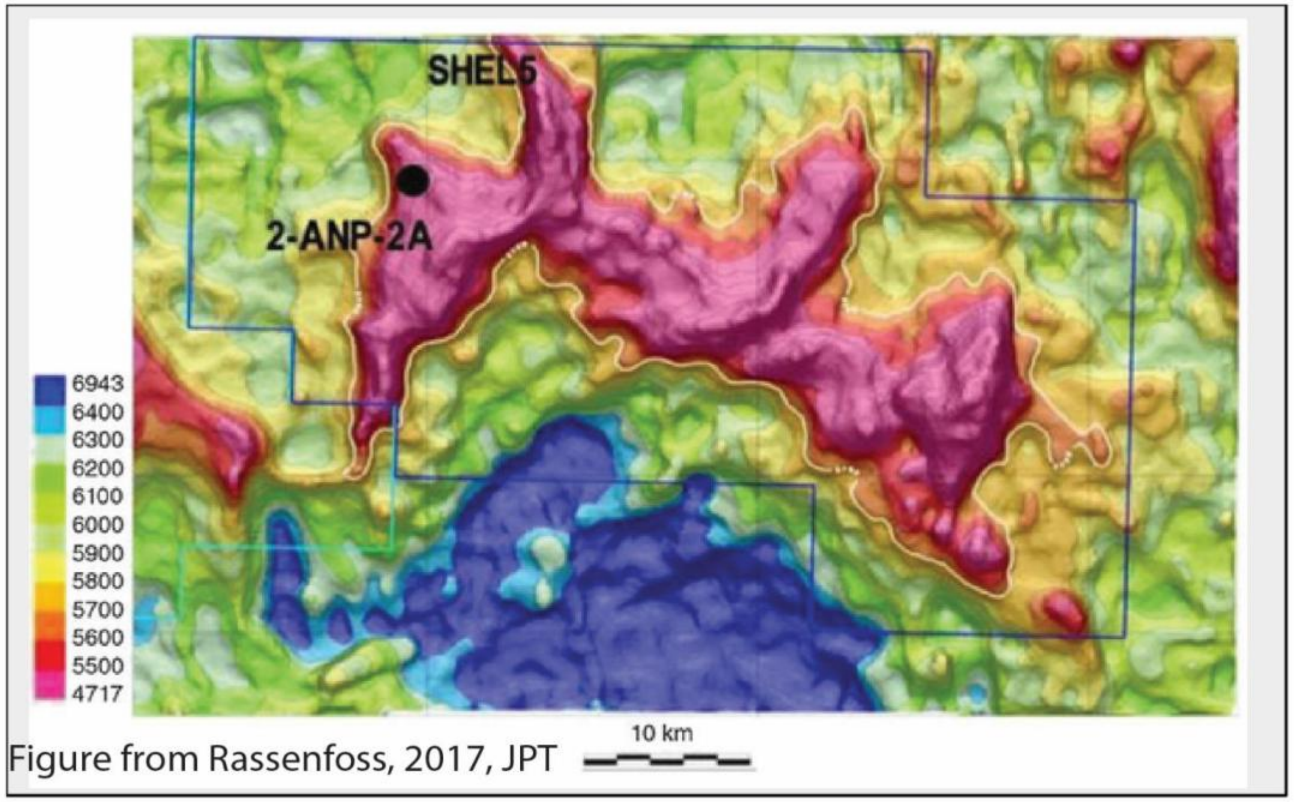


Figure from Rassenfoss, 2017, JPT

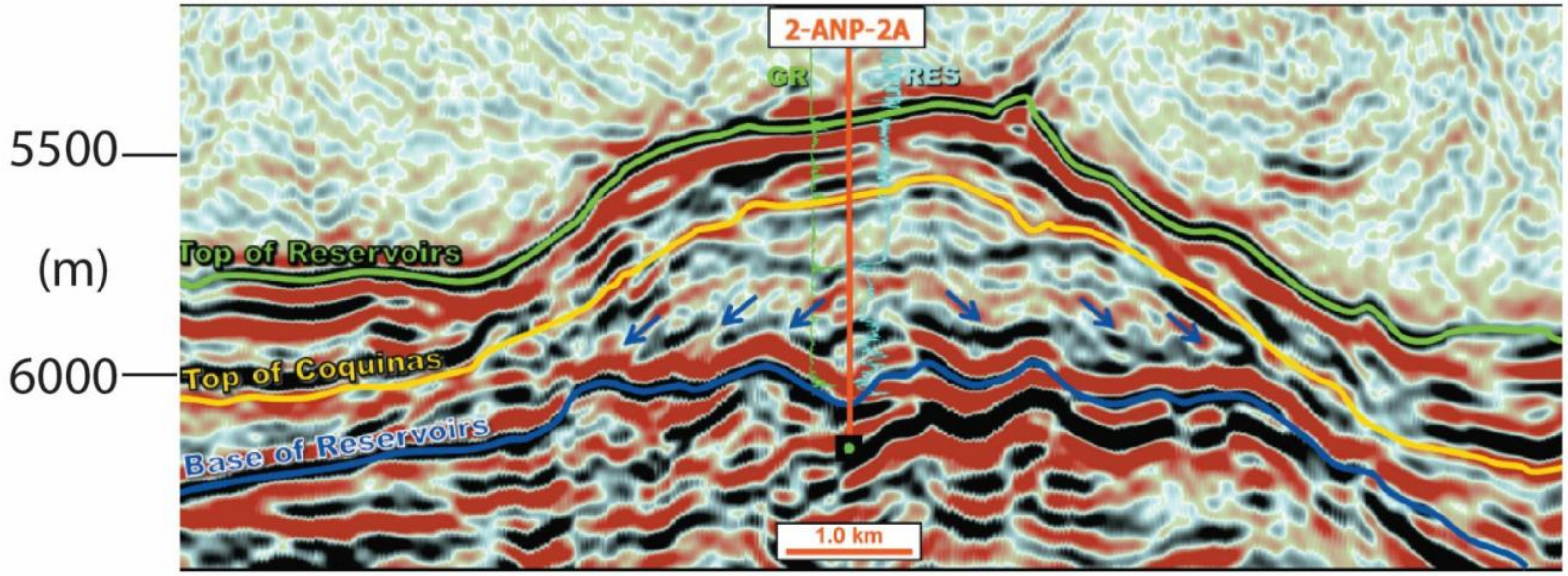
Libra field: 2010 Discovery (Petrobas)

12.725 BBOE
10 BBO, 14.25 TCF Gas

Aptian lacustrine carbonates
Syn-rift highs

Sub-salt carbonates potential
> 150 BBOE

NW Depth seismic showing microbial carbonate buildup (m) SE

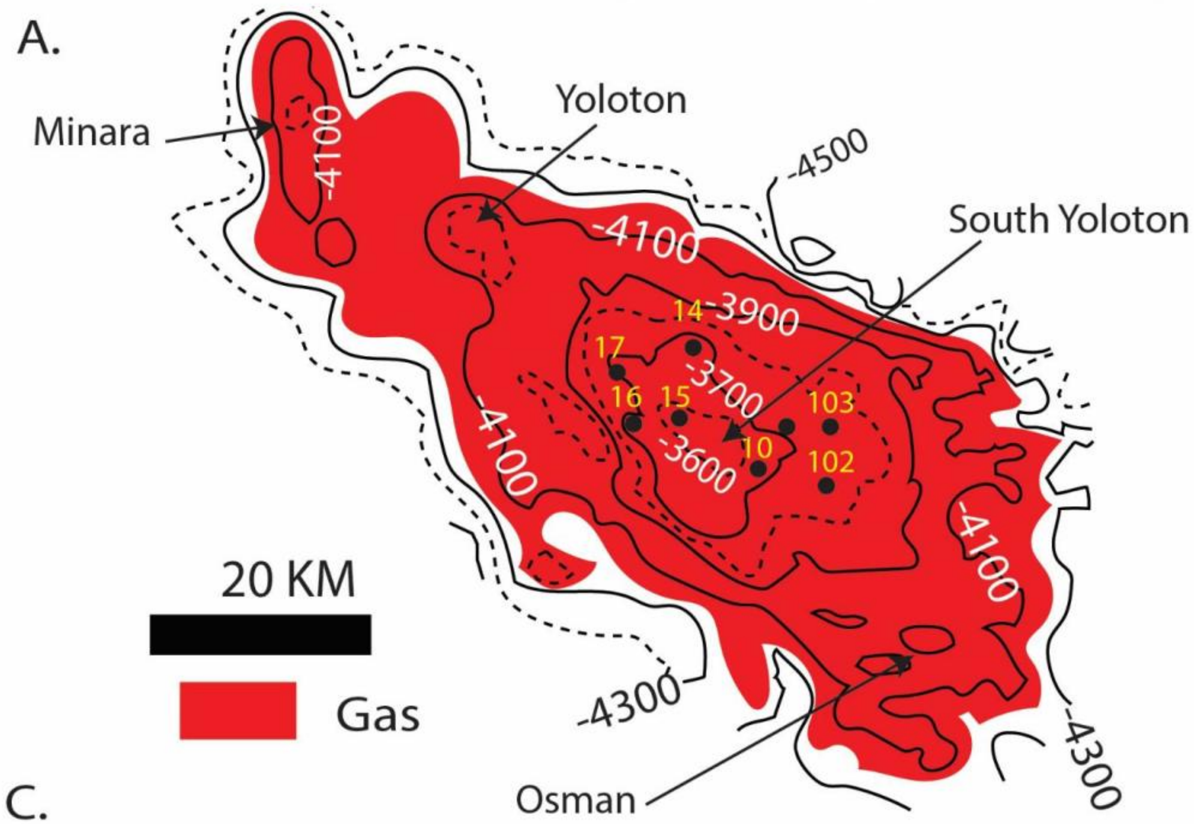


Seismic image from Carlotto et al., 2017, AAPG Memoir 113

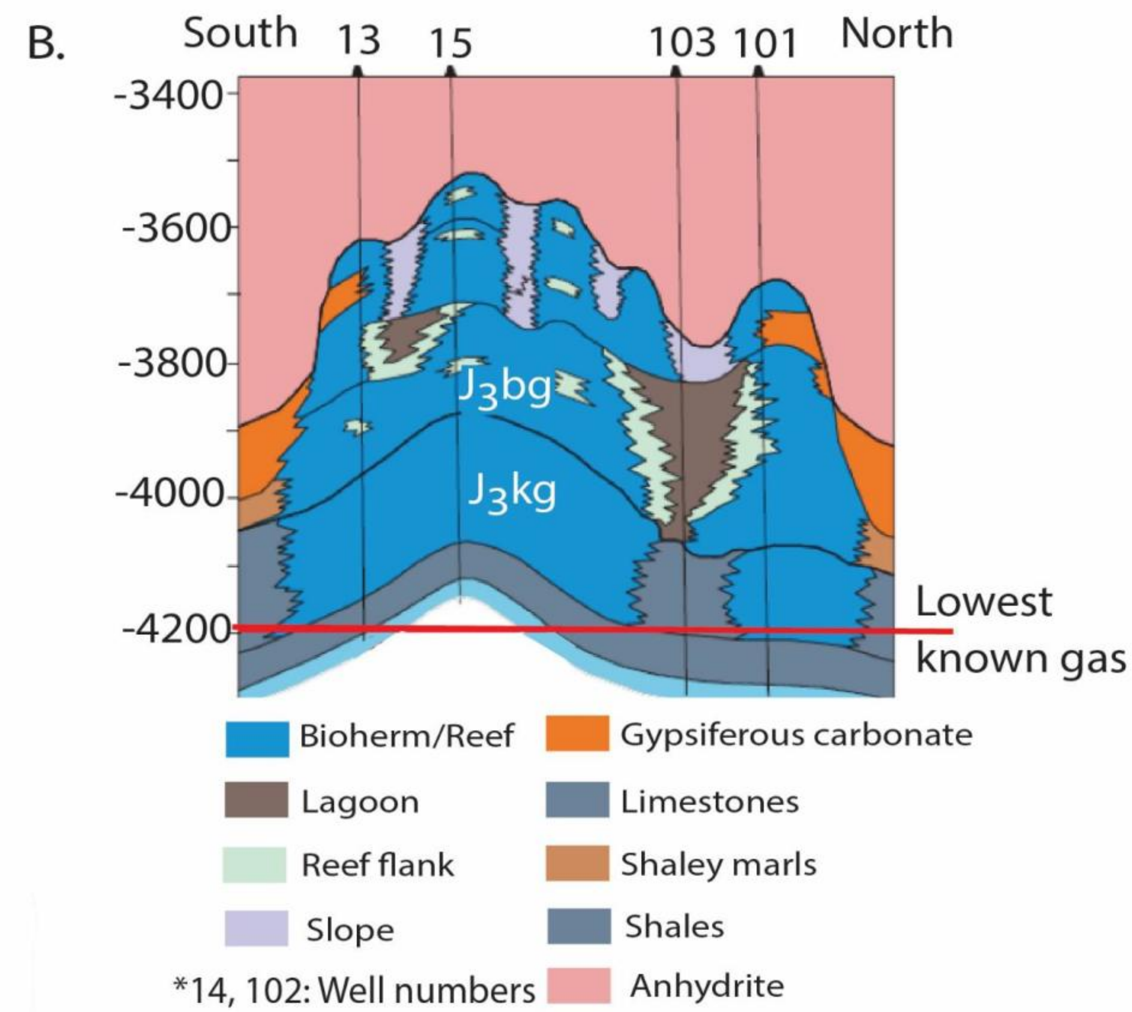
6

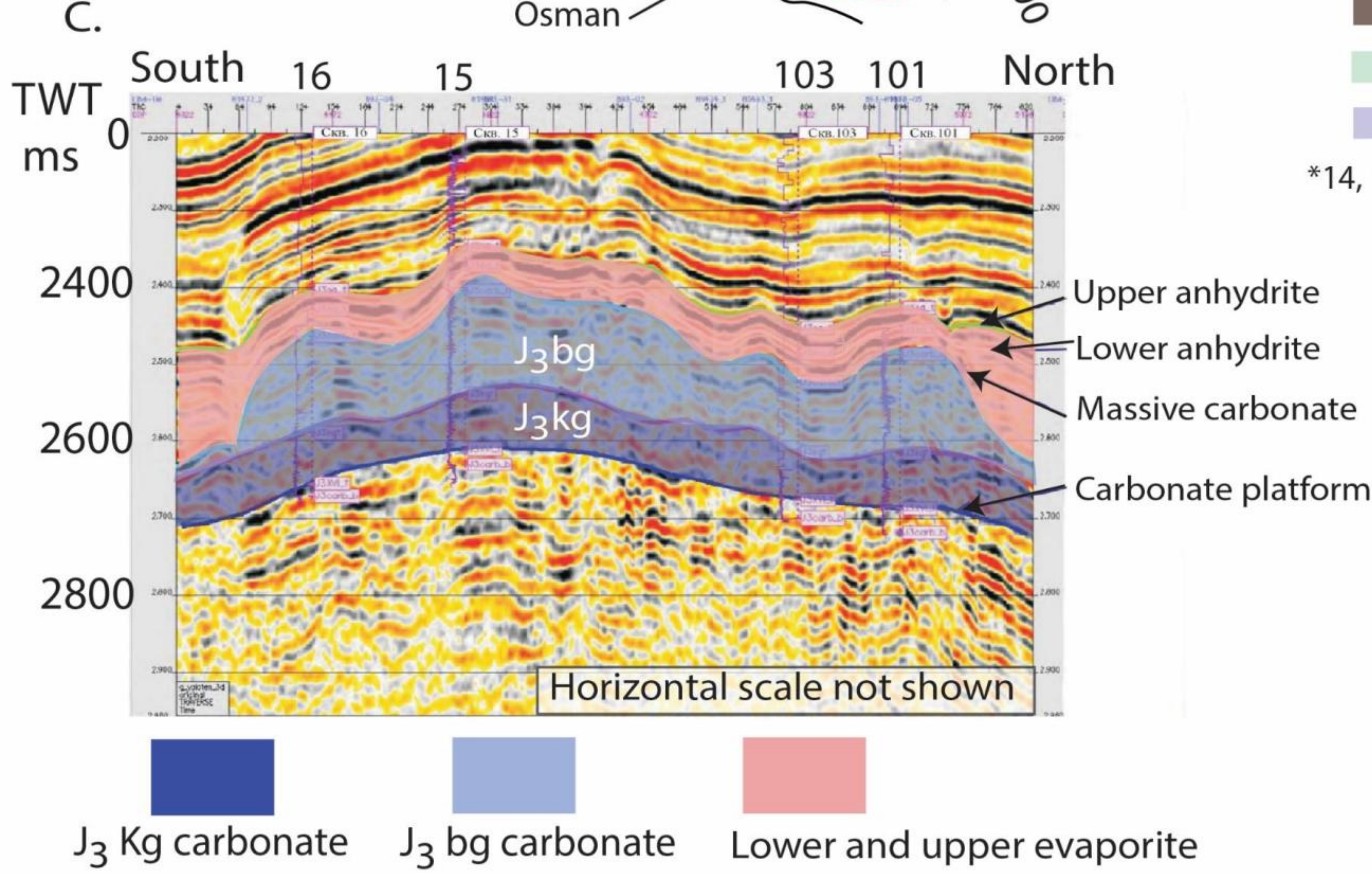
2003 Galkynysh complex

Structure map (meters) on the Upper Jurassic productive complex



South Yoloten-Osman Reef





Reserve ranges Gas Equivalent:

Solovev and Salina, 2018 (17.6 BBOE-Gazprom)

Stark and Smith, 2017: 67.1 BBOE

Avramenko et al., 2010 : Gafney/Cline ranges
Low: 23.5 Mid: 47.1; High: 82. 4 BBOE

2.143 Billion barrels oil also reported

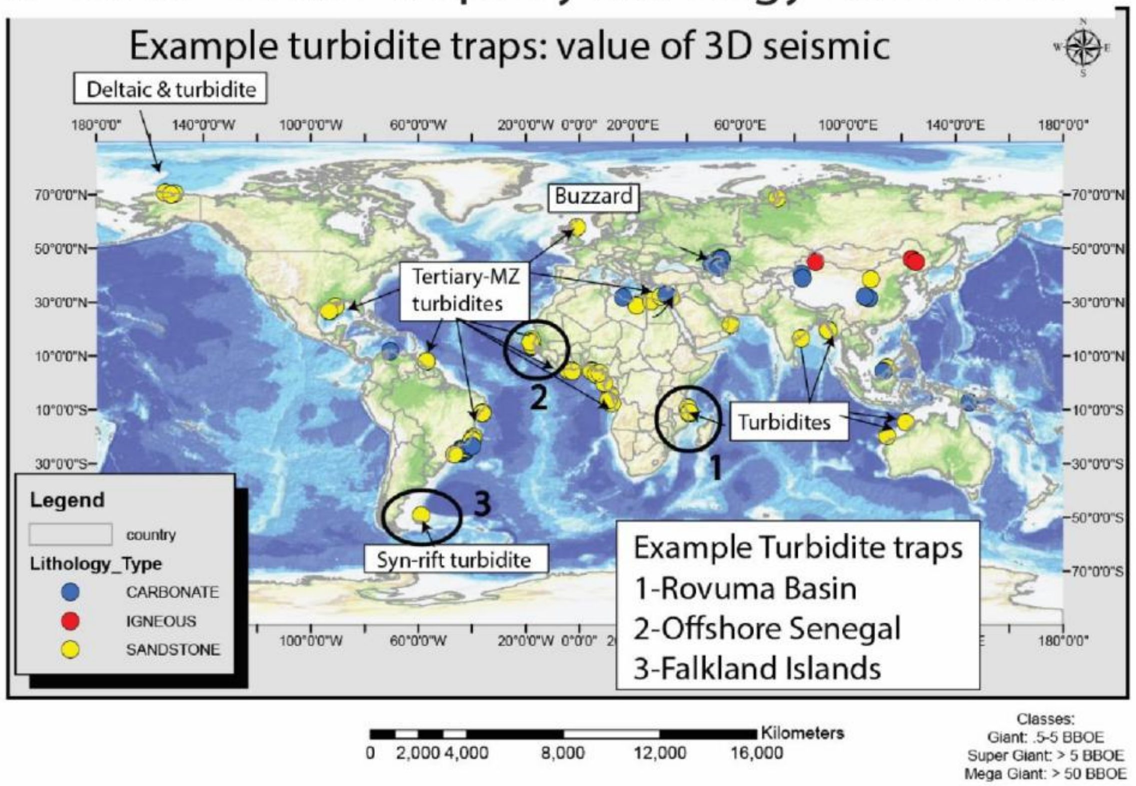
Porosity and fluids:

J_3 Kg suite porosity 1.1-13.9%
J_3 bg suite porosity; 9-19.8 %
2.8 % H_2S and 5% CO_2

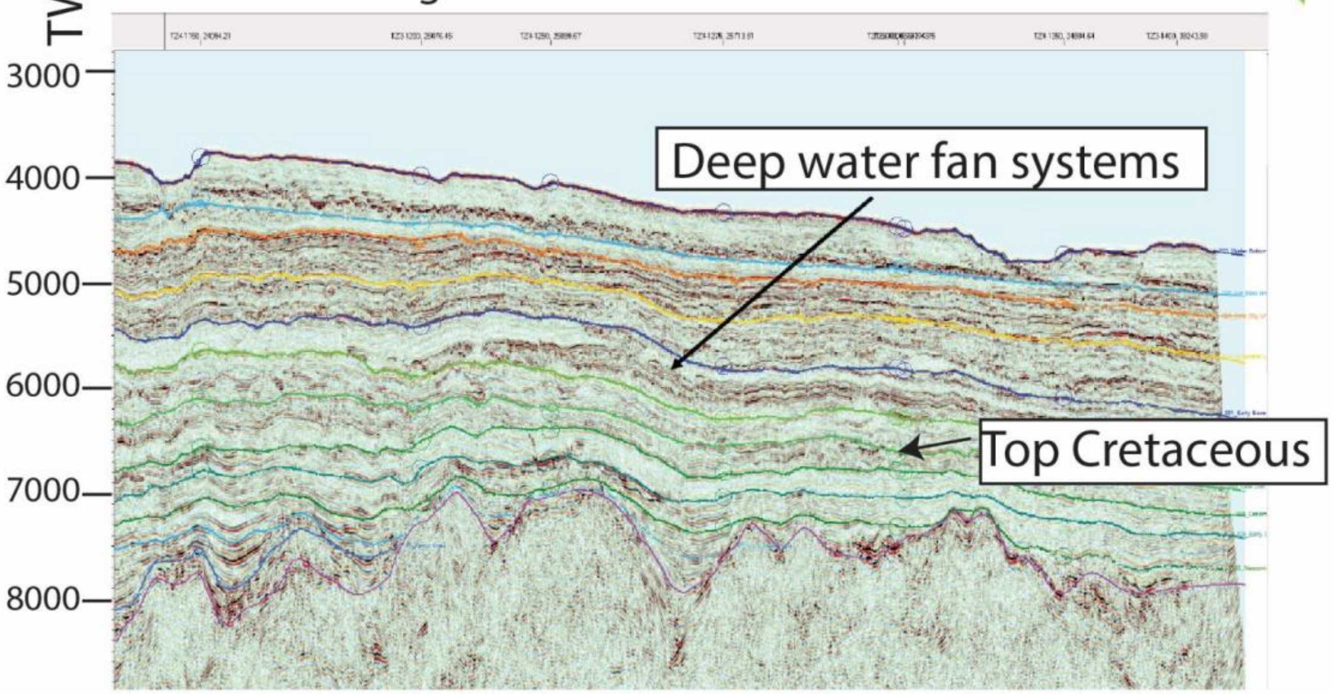
Images modified from Avramenko et al., 2010 and Khafizov, 2019

DHI driven clastic fan plays

A. Strat/Combo traps by lithology 2000-2017



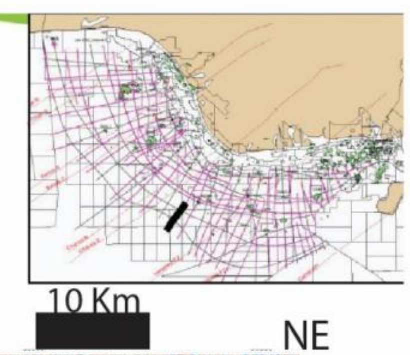
B. Prolific traps:
Thick reservoir intervals
3D Seismic images reduce seal risk

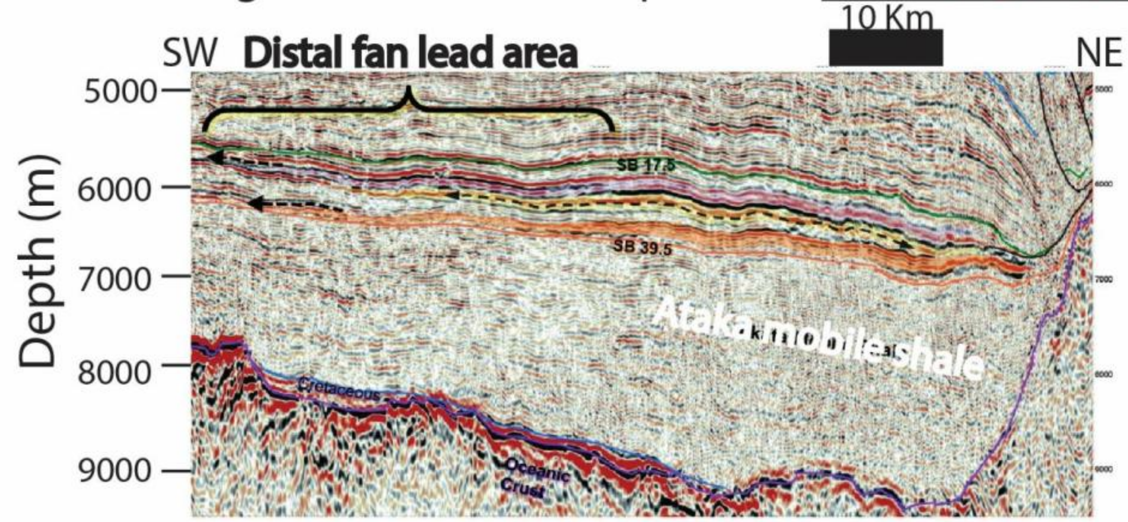


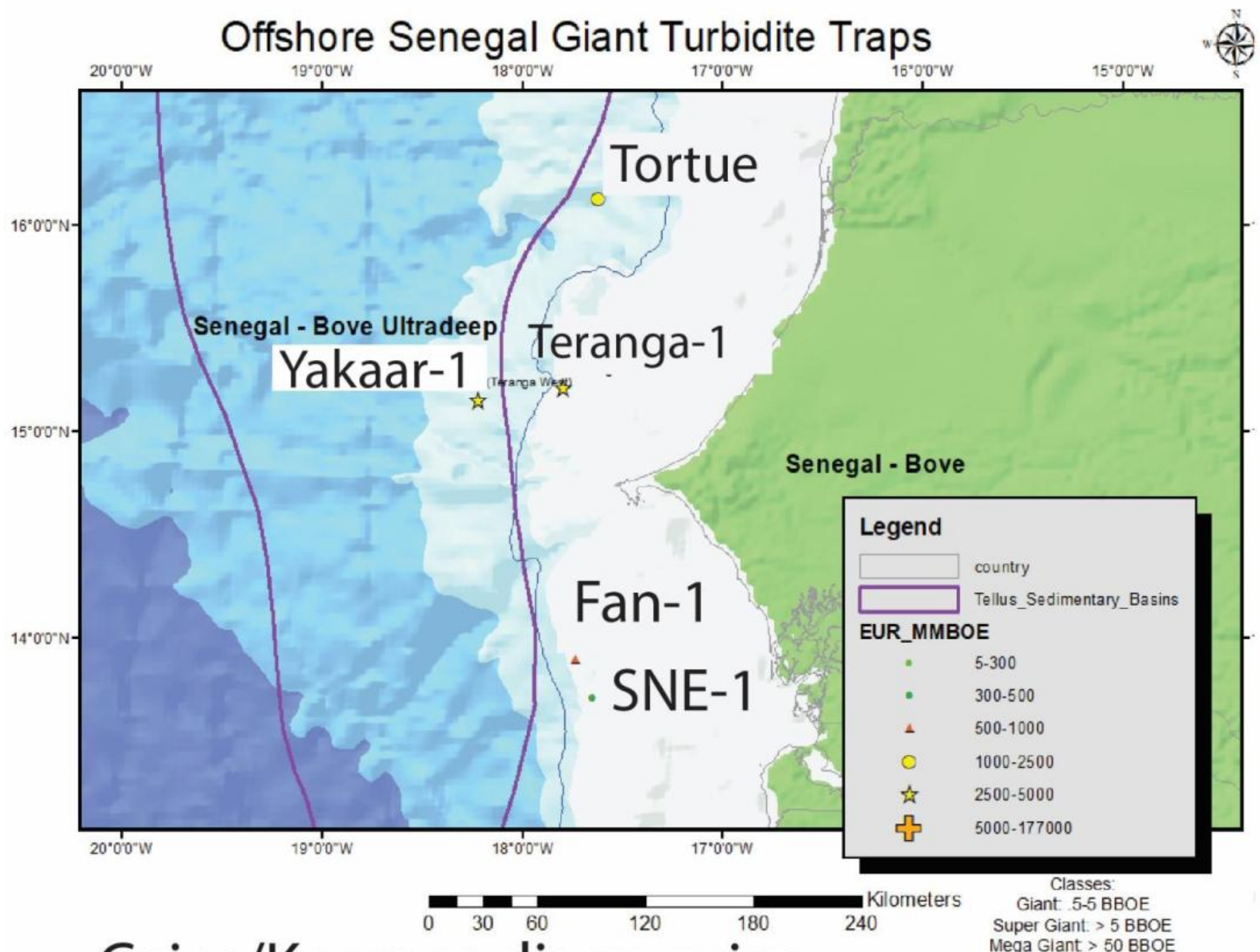
Turbidite plays:

There are no 'unique' models
3D seismic reservoir imaging vital
Don't be 'analog' driven, be data driven
DHI response has been a key factor
to reduce seal and charge risk
Plays focused on mature source rock fairways
have yielded biggest reserves, lowest
failure rate

C. New Frontiers:
Progressively deeper water
More distal facies
Huge reserve potential
Niger Delta lead example







Cairn/Kosmos discoveries

Fan-1: 2014 (Cairn)
- 950 MMBO P50; P10 2.5 BBO
- Fan-South-1 successful 31º API oil

SNE-1: 2014 (Cairn)
- Paleotopographic: 385 MMBO
- SNE-1 extensions successful

Yakaar (Teranga West): 2016: 15 TCF (Kosmos)
Tortue: 2015: 15 TCF (Kosmos)
Teranga: 2016: 15 TCF, 300 MMBO

Mature kitchen/source rock strat traps

Play schematic

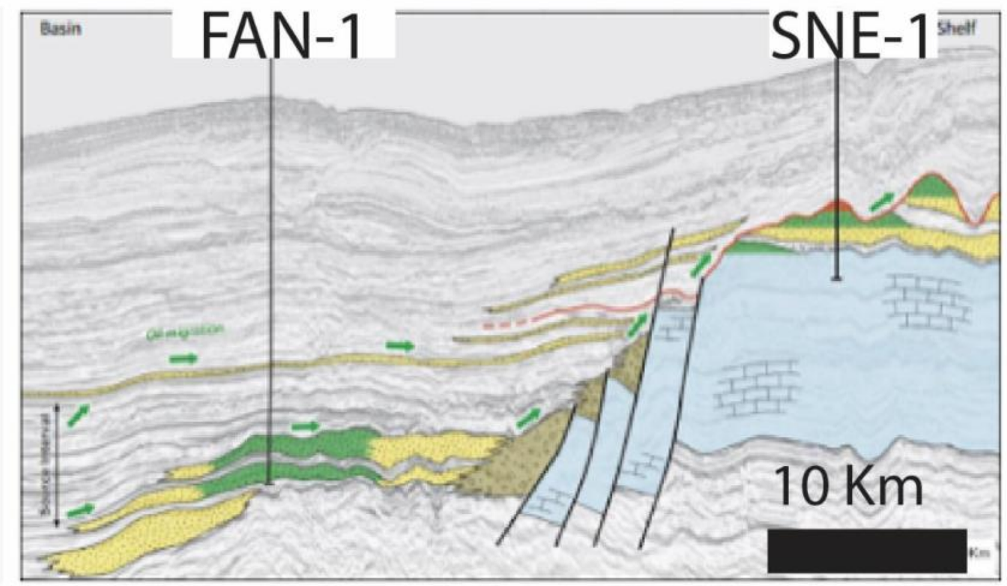


Figure from Reynolds, 2016

FAN and SNE Discoveries

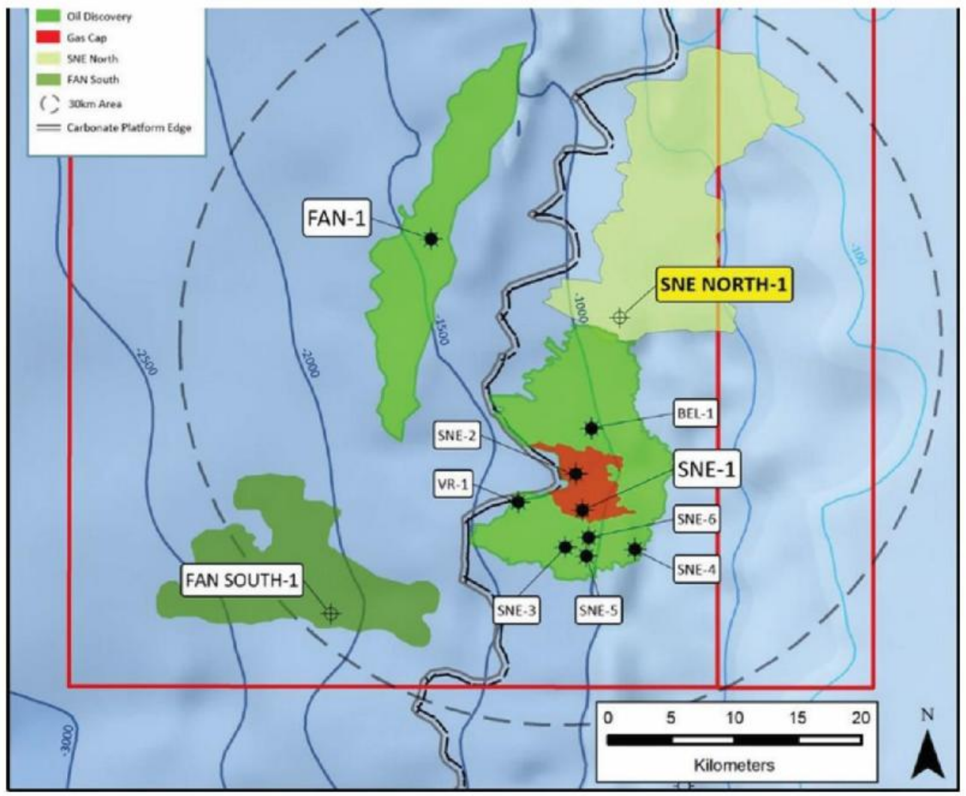
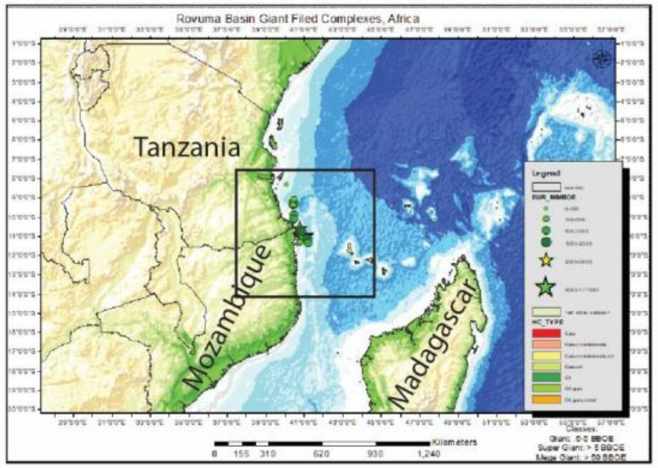


Figure from Cairn August 7, 2017 press release

Rovuma Basin Mamba Complex



Mamba Complex

2011 Discovery
53-80 TCF, 150+ TCF in trend

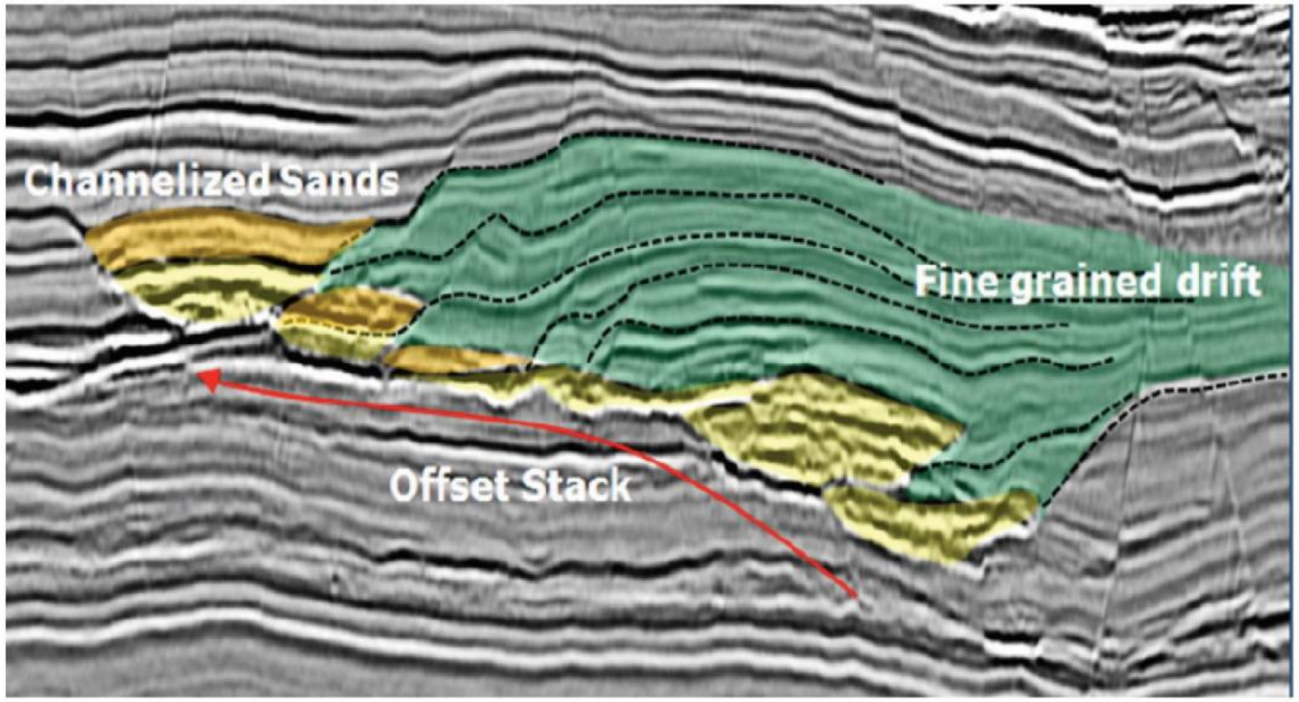
Cretaceous, Paleocene-Oligocene turbidite channel complexes

Play initiated by Cove Energy, ENI and Anadarko

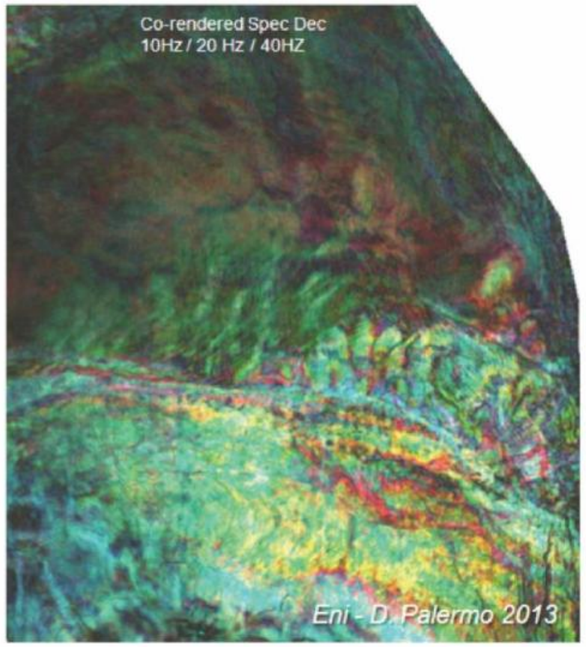
Coral Example (right)
2012 Discovery
10.4 TCF, 16 MMBO Cond.

3D seismic + DHI driven success

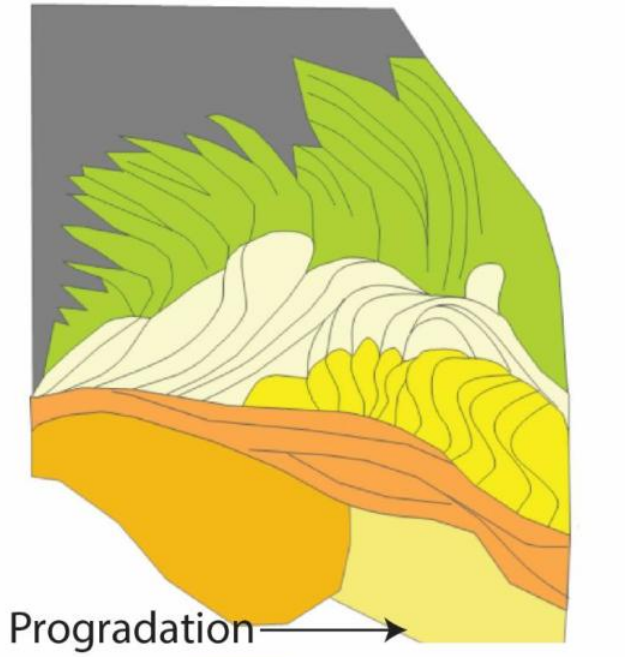
North — Seismic section — South



Spectral decomposition



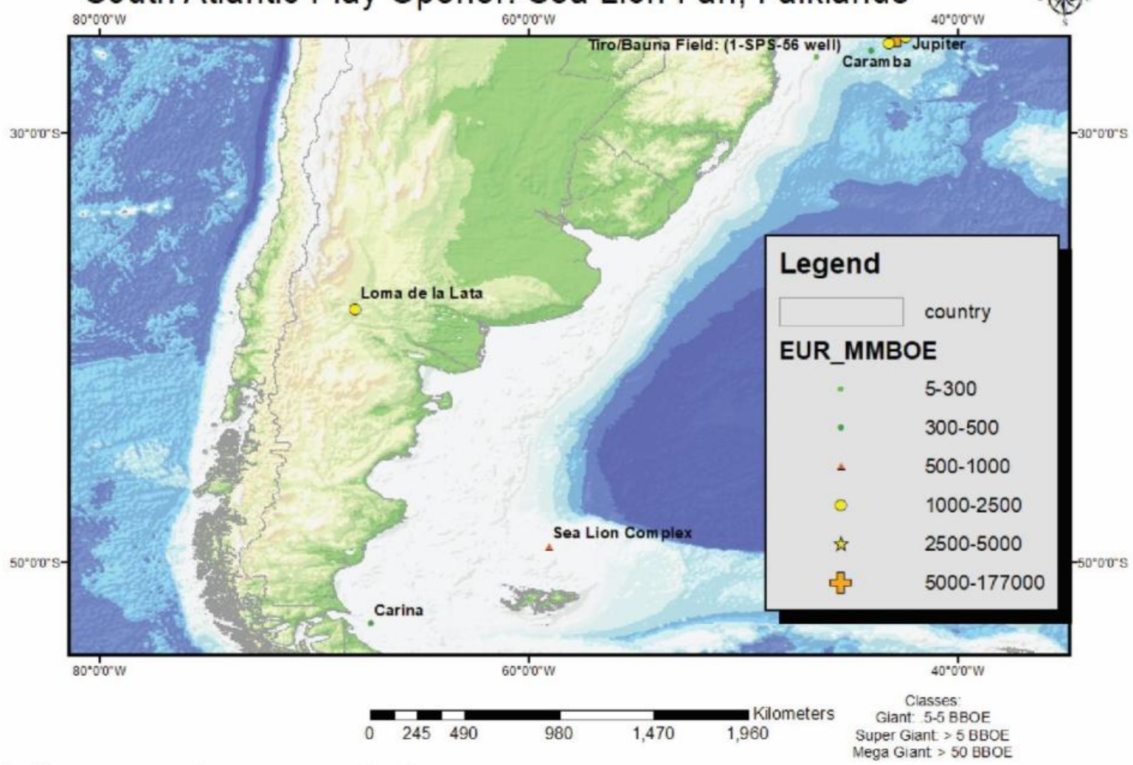
Interpretation: Coral reservoir

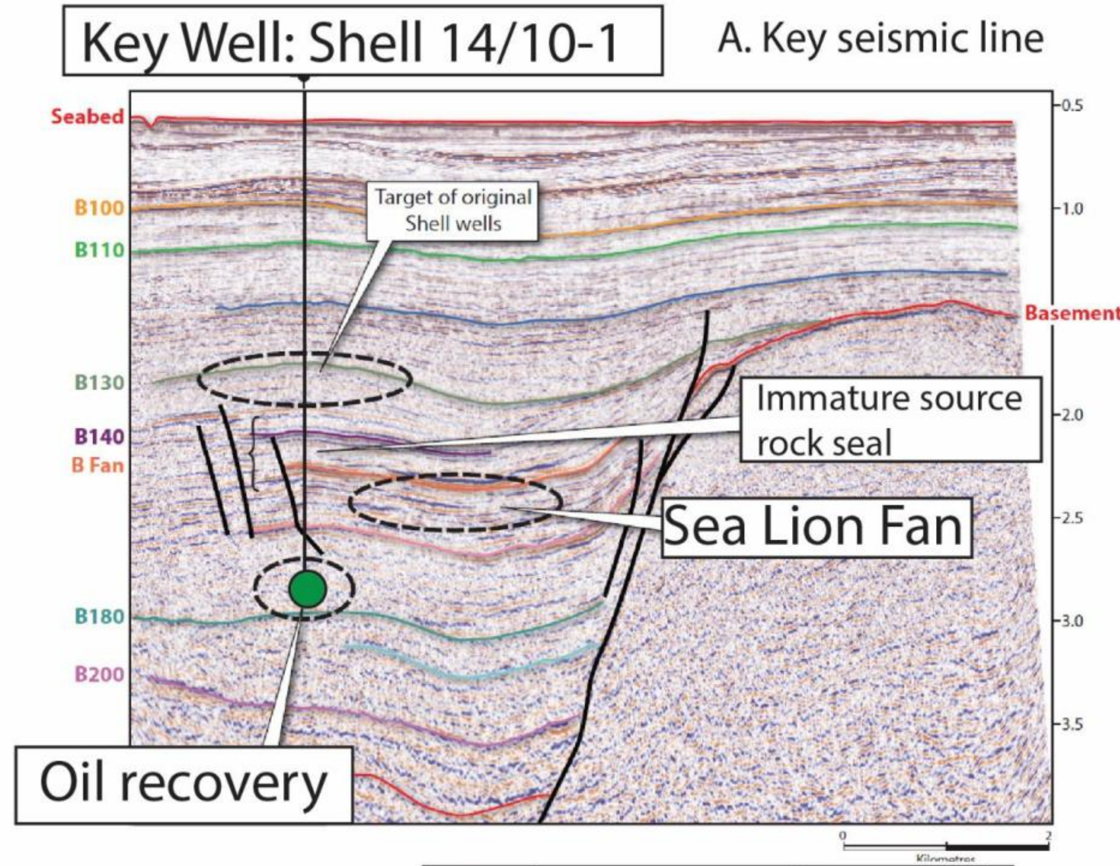


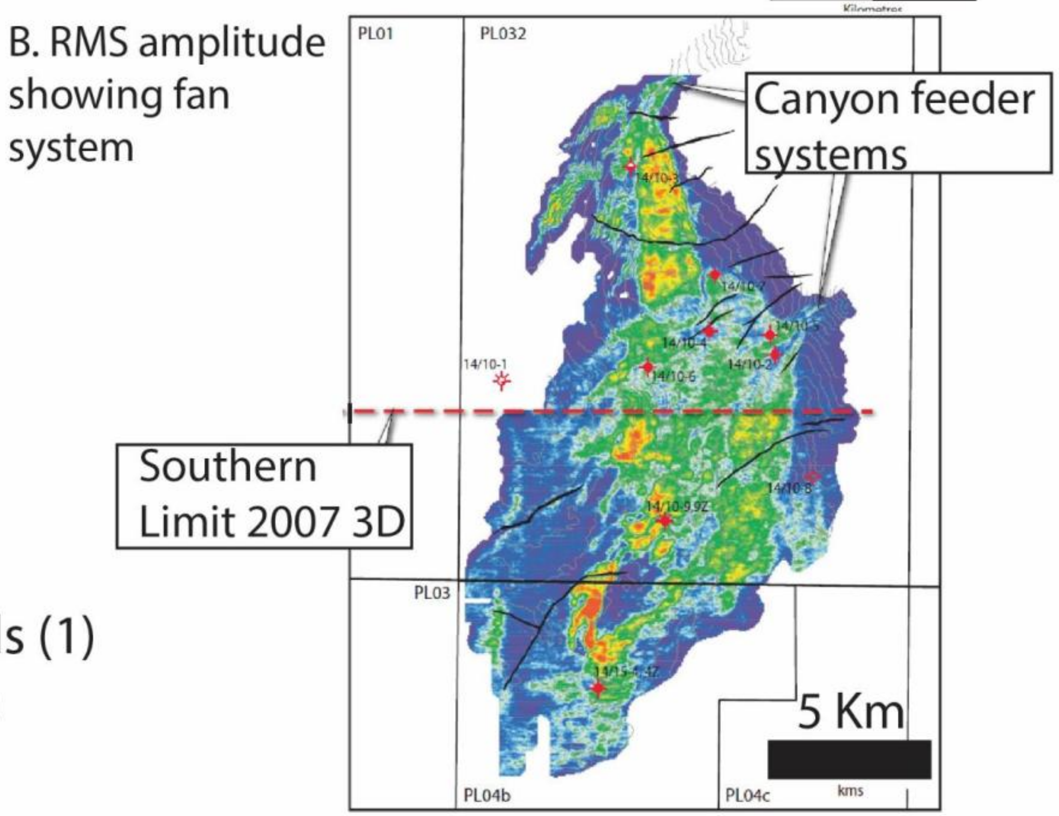
Images modified from Fonnesu, 2013 and Palermo et al., 2014

Giant/Significant Strat Traps to 2017

South Atlantic Play Opener: Sea Lion Fan, Falklands







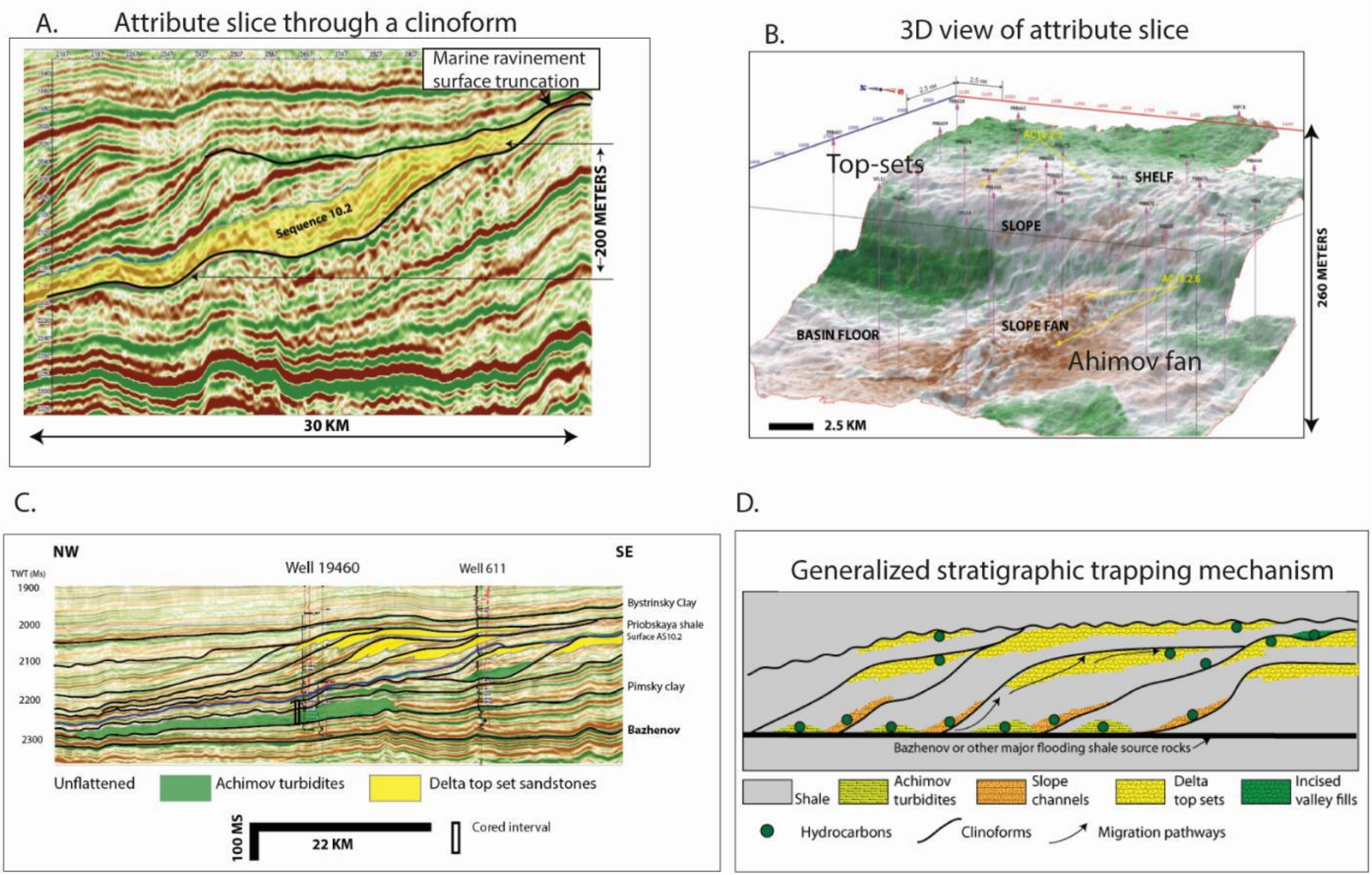
Figures modified from MacAulay, 2015, GEOLSOC

A lesson in creativity

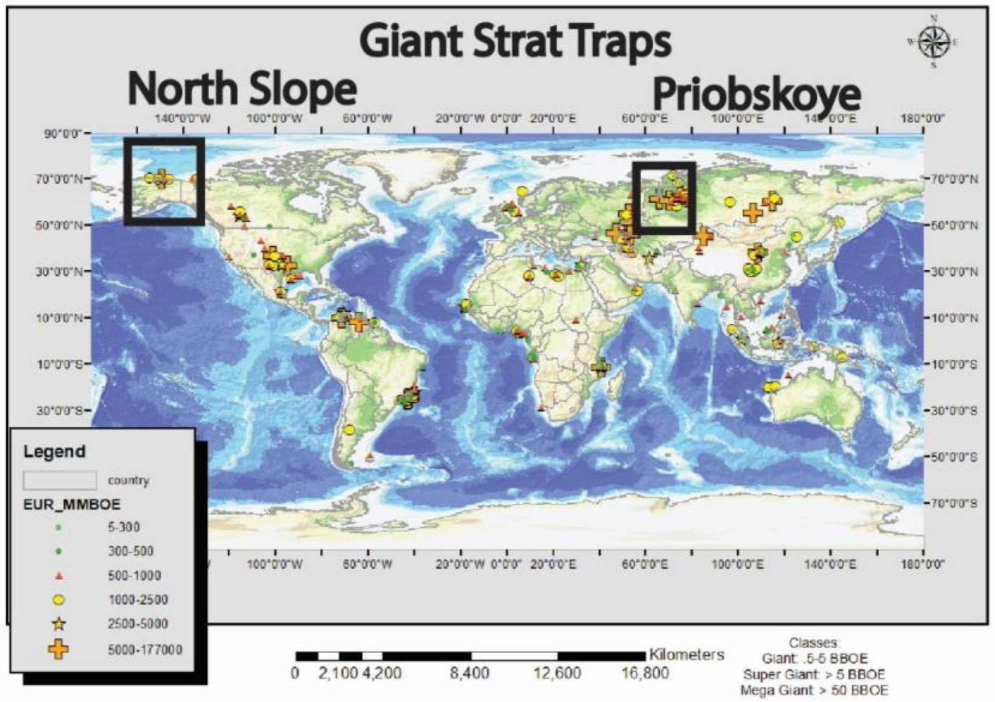
Sea Lion Fan: 2010, Rockhopper Oil
- 770 MMBO; trend will be bigger
- Lower Cretaceous syn-post rift
- 3D seismic keying off past failures

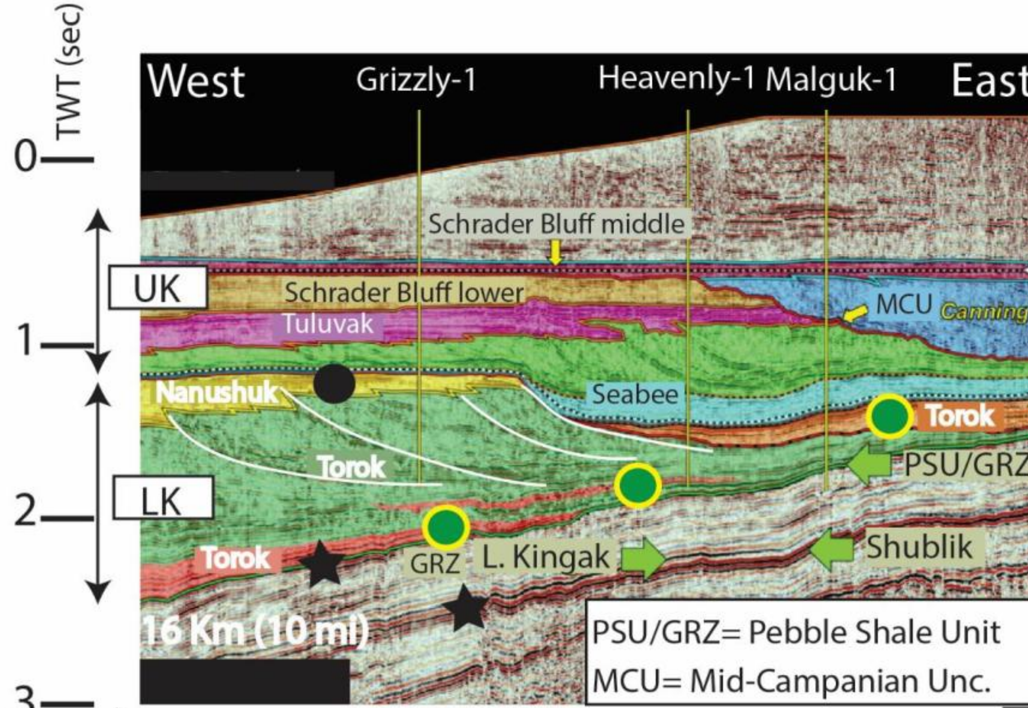
1998 Drilling campaign (6 wells)
- Inversion structural targets
- Amerada Hess (2); Shell (2); Lasmo (1); IPC Falklands (1)
- Dry, non-commercial; proved hydrocarbon system
- Shows in all but one well
- Proved world-class lacustrine source rocks

Old concept: the ‘bread and butter’ play in West Siberia, Russia: Clinoform, topset, turbidite plays—overlooked in the West?



Analog: old ideas (Priobskoye model) applied to new area: North Slope, Alaska





Atlantic margin and Russian clinoform type play applied to North Slope

Overlooked clinoform and turbidite play in mature source kitchens

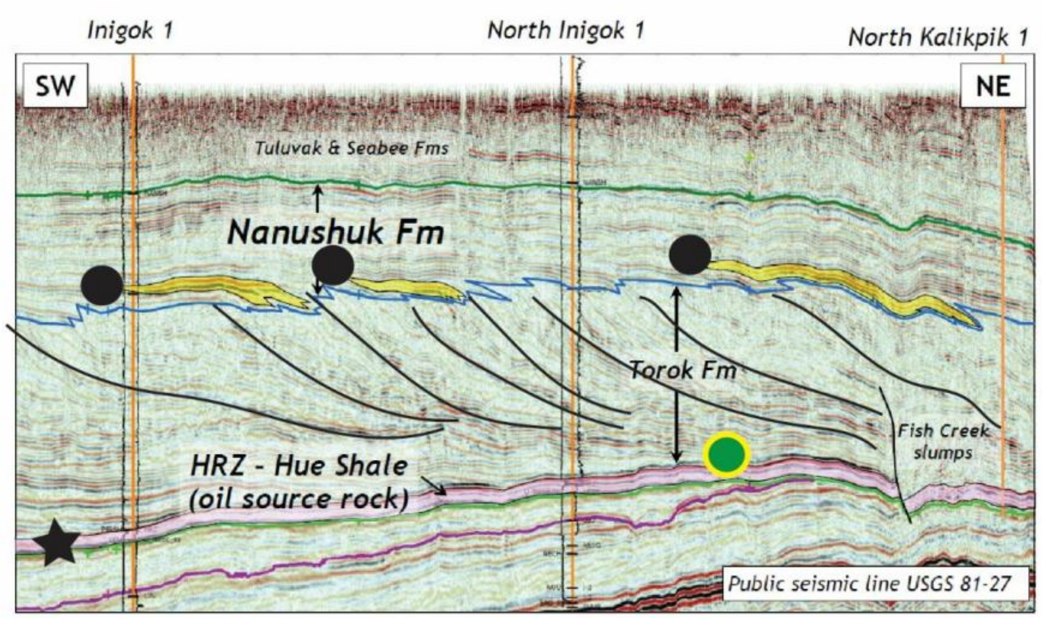
Historical focus: Prudhoe Bay Triassic Shublik

★ Main source rocks
Torok turbidite play
Topset clinoform play

Topset fields:
Hoseshoe, Pika: 1.4 BBOE (Armstrong, Repsol)
Willow: 300 MMBOE

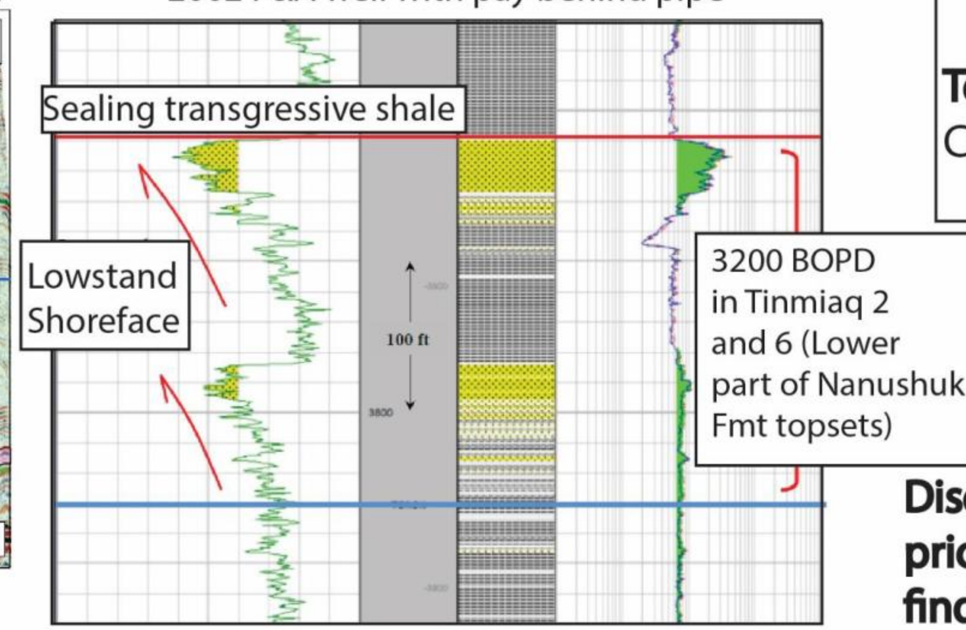
Torok Turbidites
Caelus Smith Bay (2 BBOE +) 700 km^2 trap

Play rediscovered: Conoco, Caelus, Repsol, Armstrong 2015-2017



Figures modified from Alaska Dept.Nat. Resources, 2017

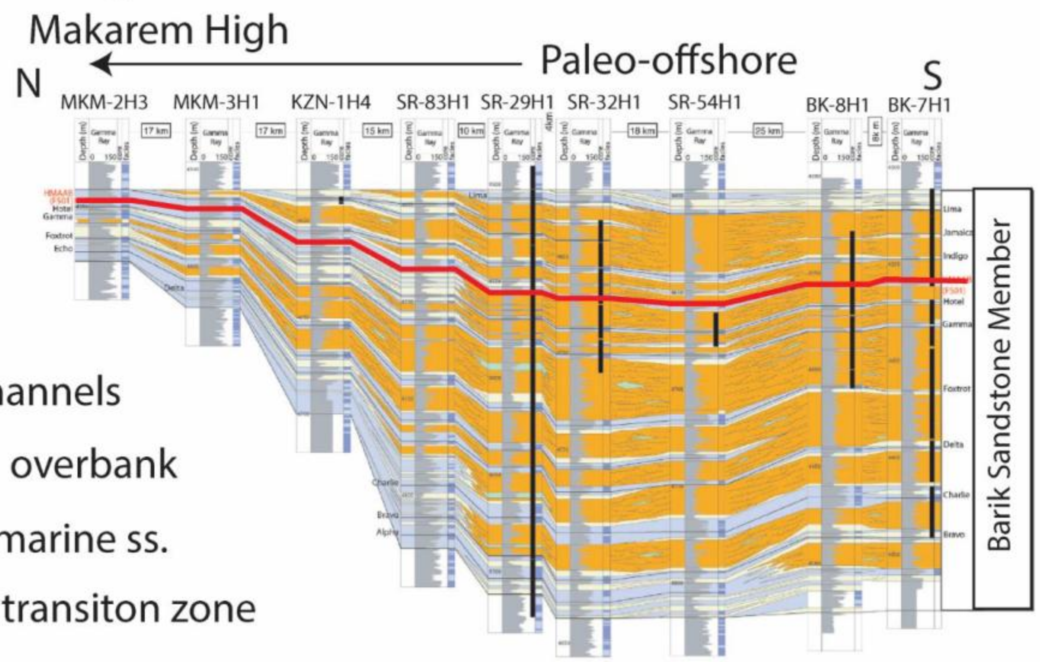
2017 Conoco-PHillips Willow Discovery keyed off 2002 P&A well with pay behind pipe



Willow Discovery

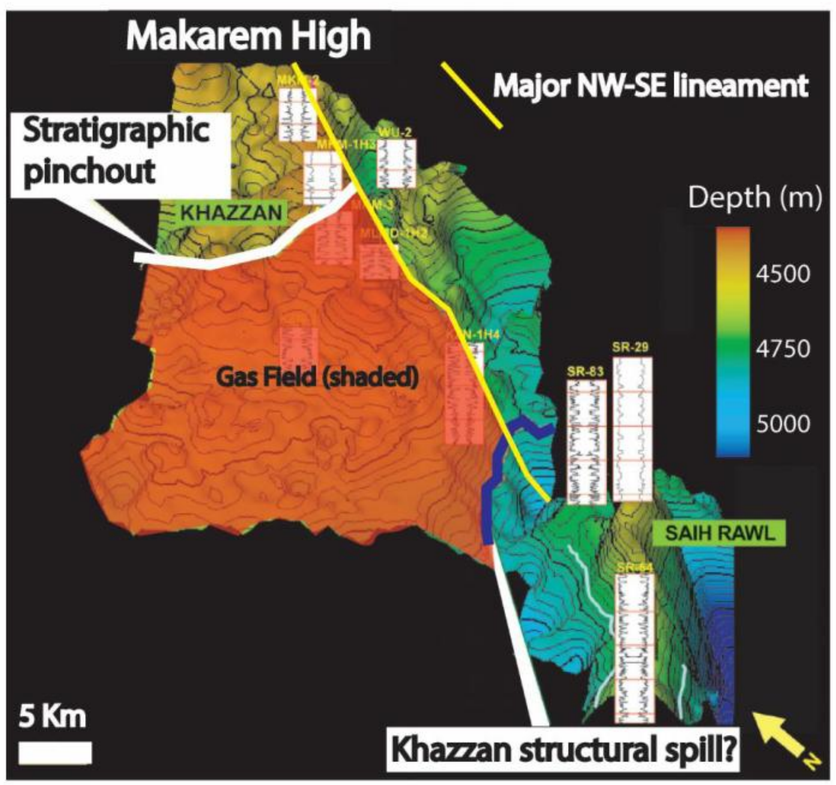
Discoveries have exceeded all prior USGS estimates of yet-to find for North Slope

Khazzan Tight Gas Field-Late Cambrian (Oman)



Fluvial channels
Mud-rich overbank
Shallow-marine ss.
Offshore transiton zone
Maximum flooding surface

2001 Discovery:
2011: 11.9 TCF
2020: 25+ TCF?

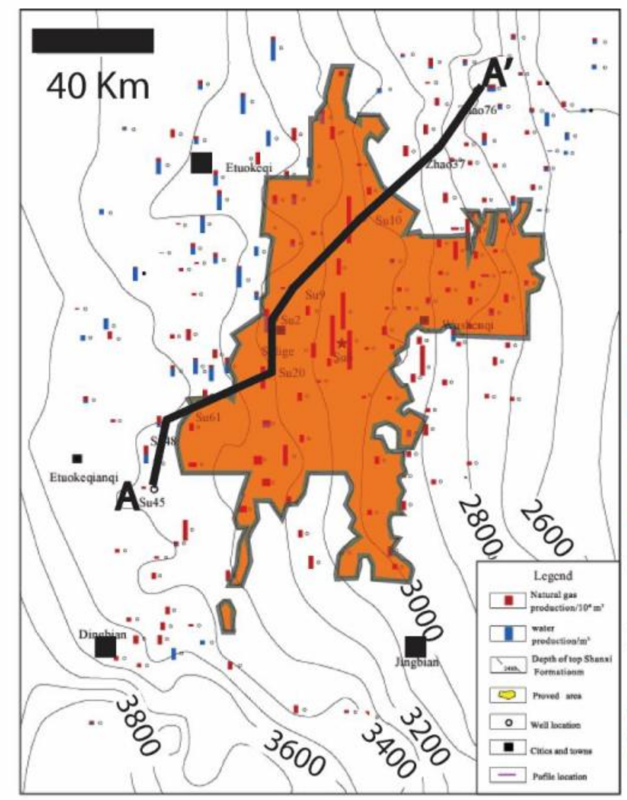


Combination trap downdip of structural high.
Trap still poorly understood.

Figures modified from Millson et al., 2008, AAPG Bulletin

Sulige Field: Ordos Basin, China

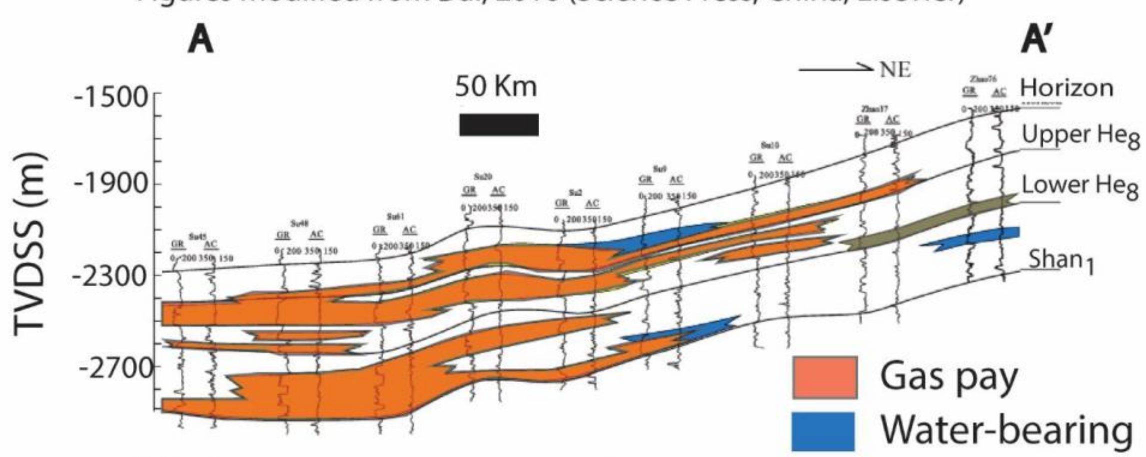
Structure depth, top Shanxi Fmt.



Permian tight sand: coal-sourced

Gas production $10^4/m^3$
Water production $10/m^3$
Well location
Cities
Field outline

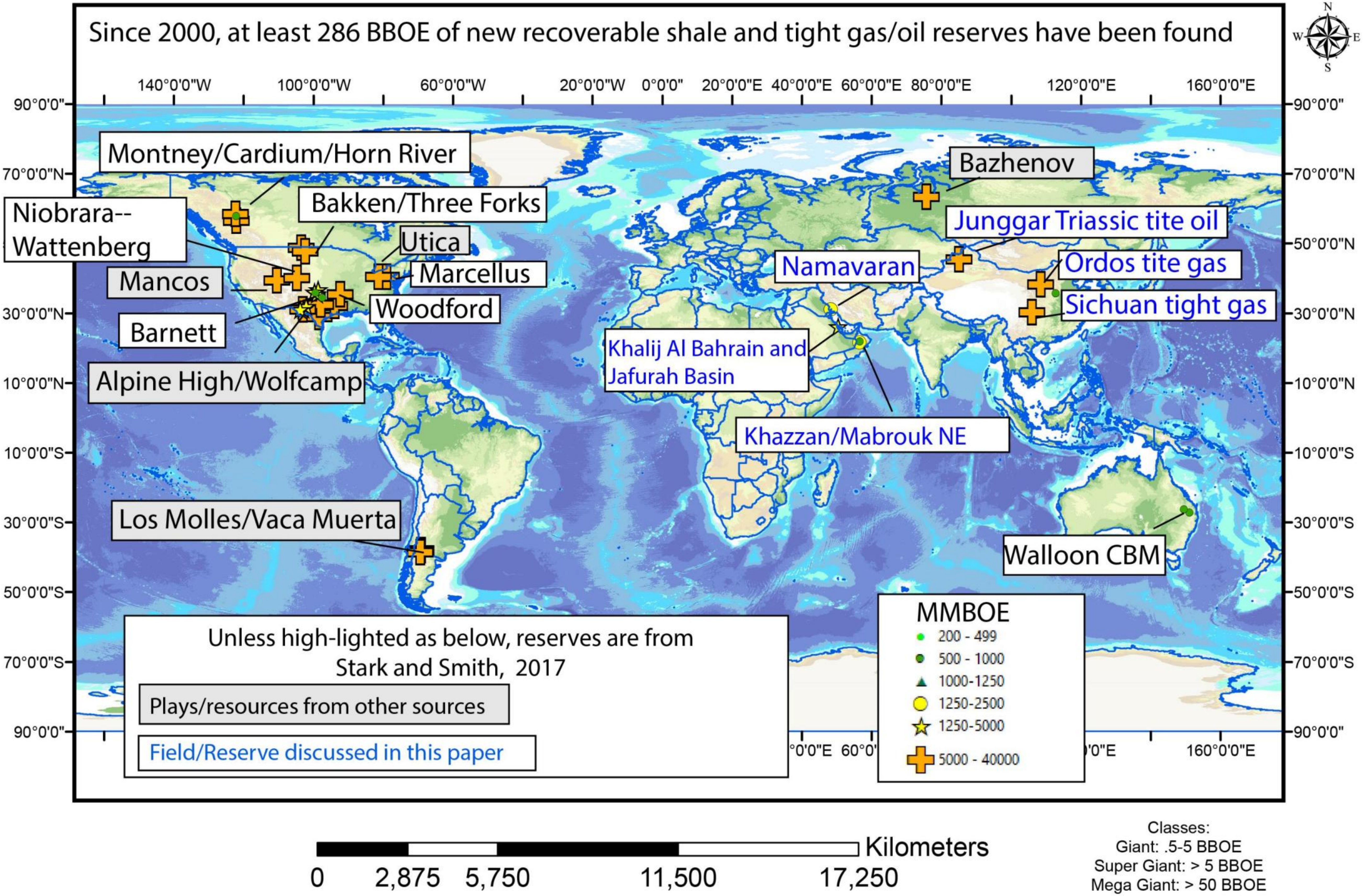
Figures modified from Dai, 2016 (Science Press, China, Elsevier)



Major reserve growth

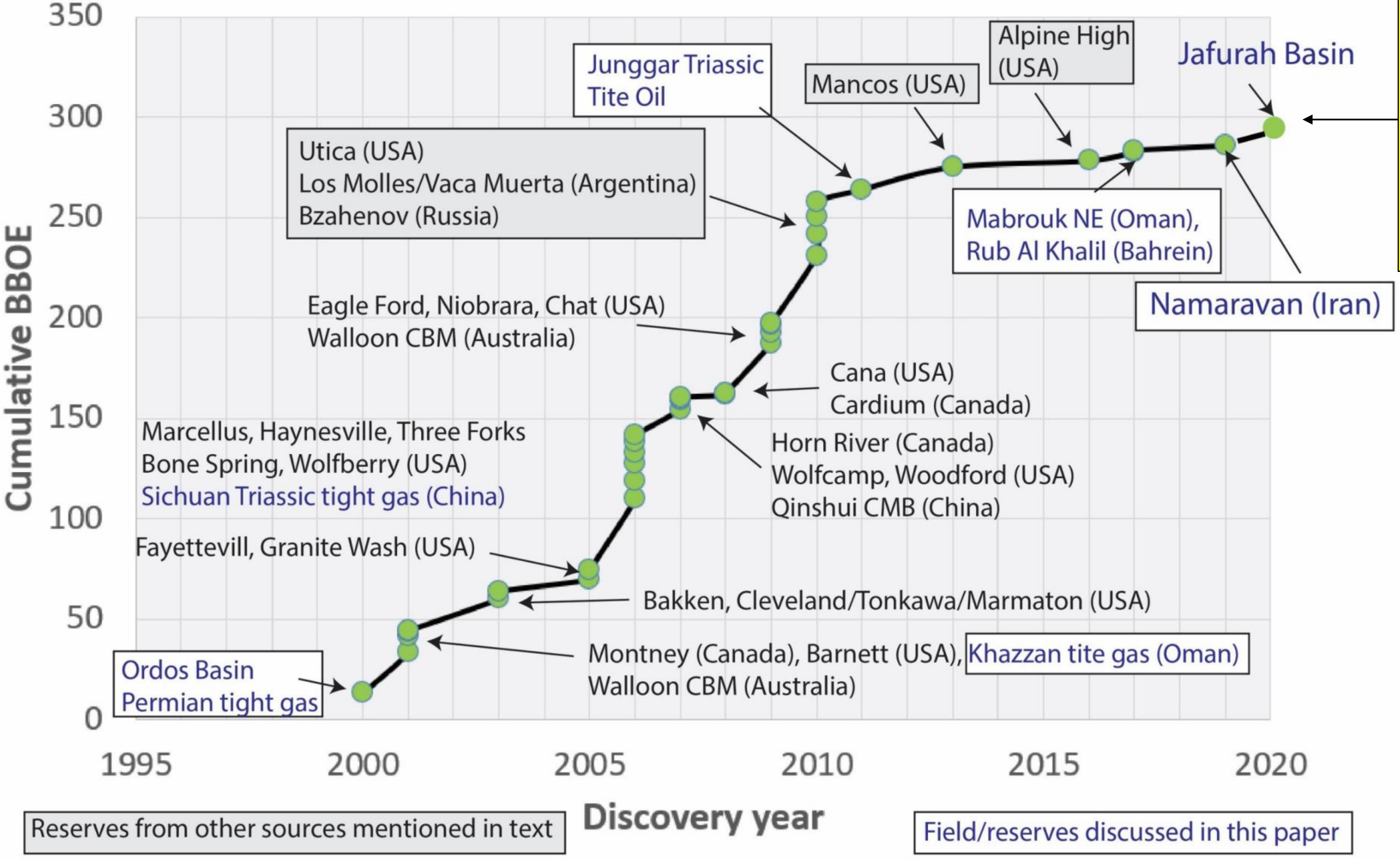
2000 Discovery, size not realized. 36,000 Km2 trap (minimum).
2006: Entire Ordos Basin given 18 TCF from all traps
2016: Sulige Field alone estimated 44 TCF (7.3 BBOE)
*Ordos Basin Permian fields 80 TCF proven
*145 TCF basin potential

Active unconventional and tight oil/gas plays since 2000



Classes:
Giant: .5-5 BBOE
Super Giant: > 5 BBOE
Mega Giant: > 50 BBOE

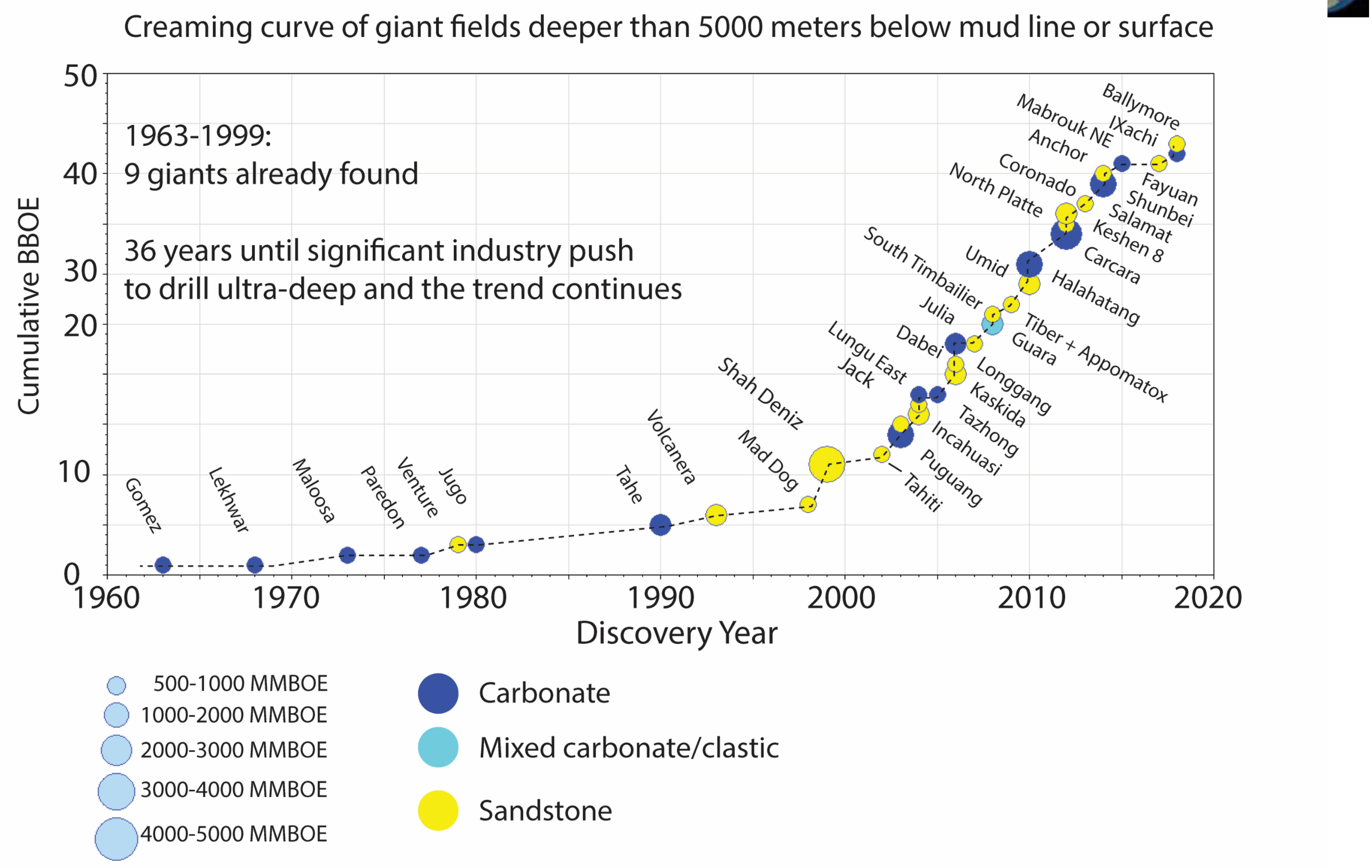
BBOE recoverable active unconventional shale and tight oil/gas plays
(Unless highlighted, reserves are from Stark and Smith, 2017)



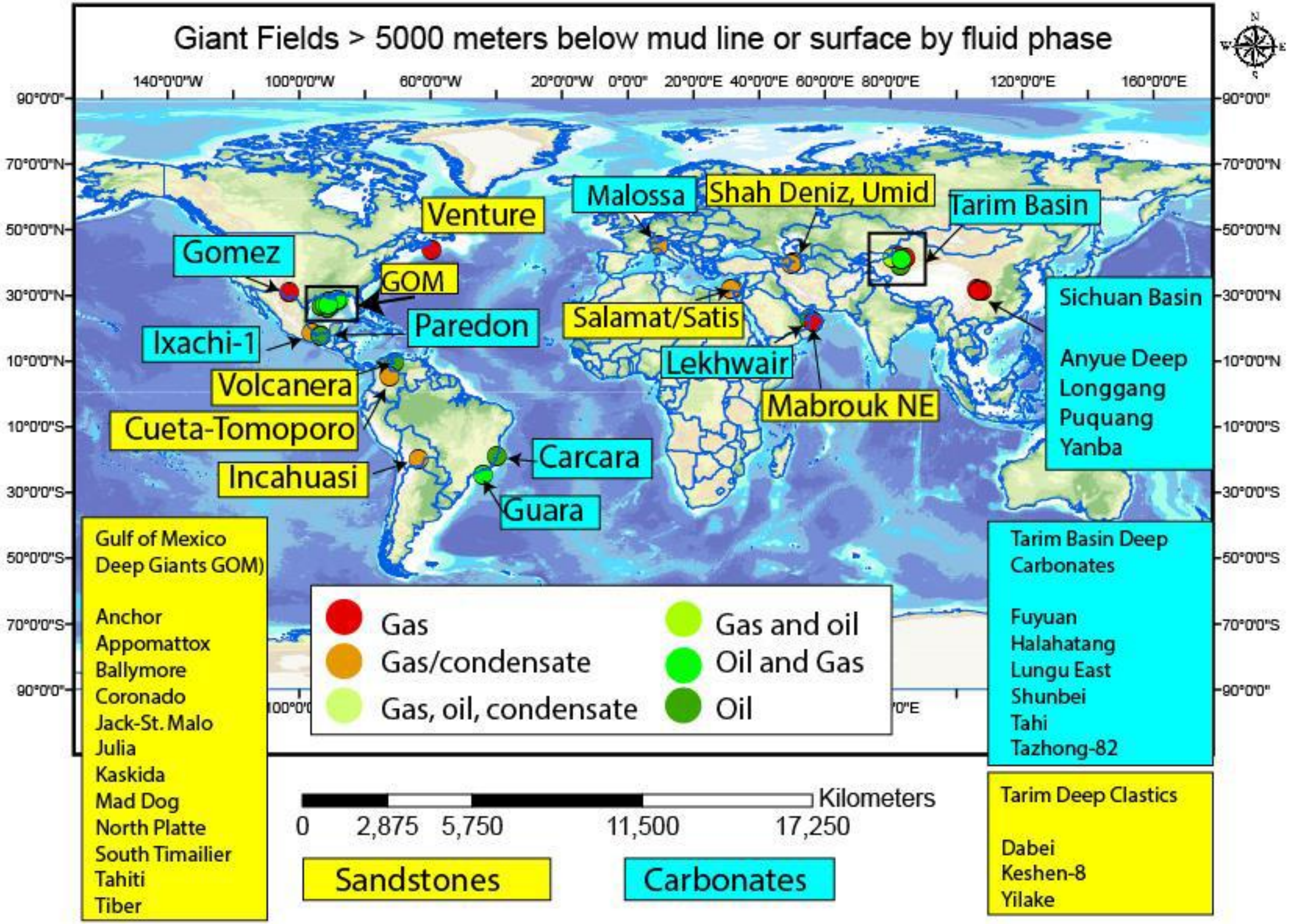
Jafurah Jurassic: 270 TCF resource- Only 5.8 TCF booked by Wood-Mac (Latham, 2021)

(Dolson et al., 2021, Giant Fields Memoir)

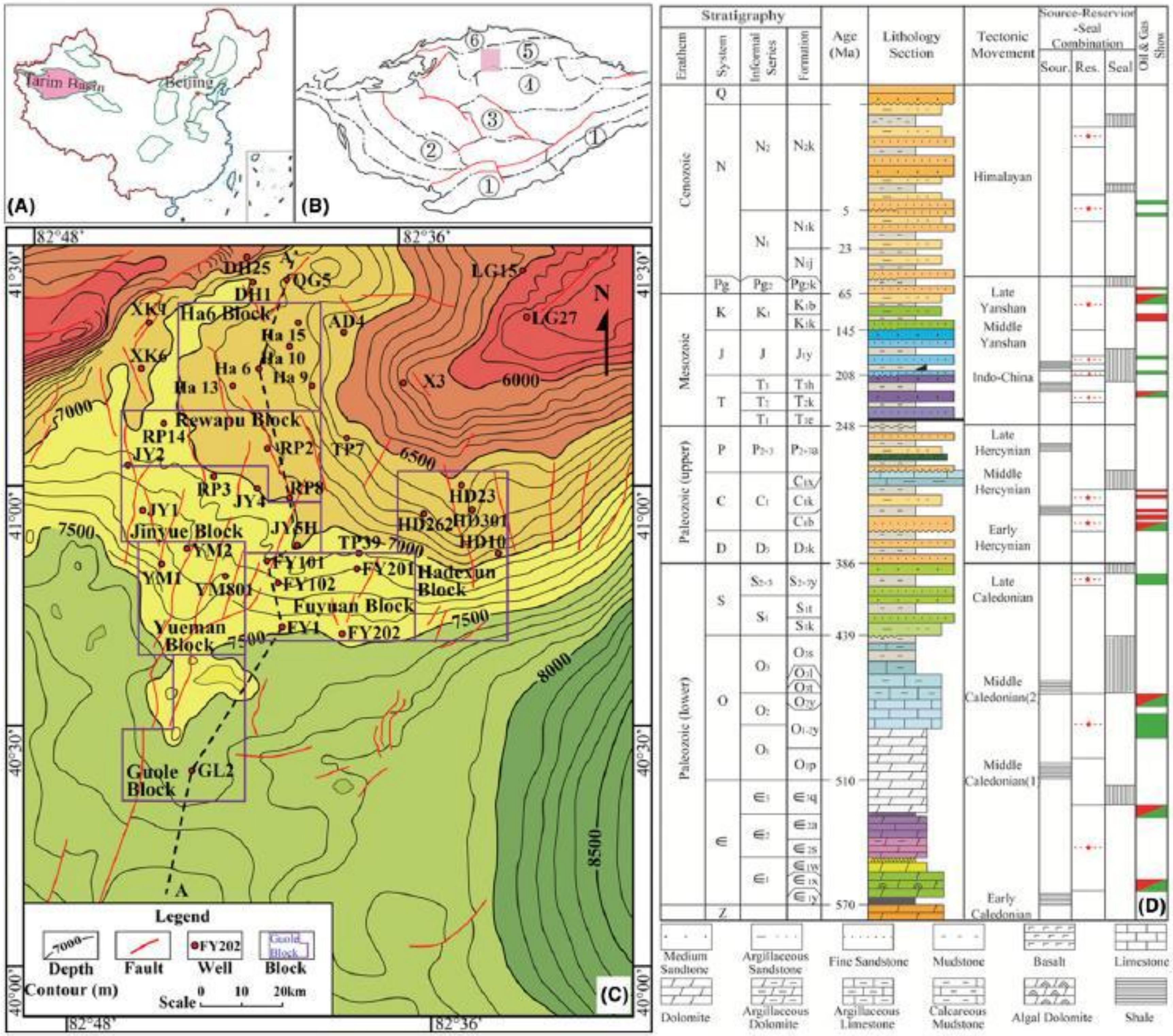
Drilling deeper below mudline…



Deeper and deeper drilling and more liquids in high pressure, high temperature

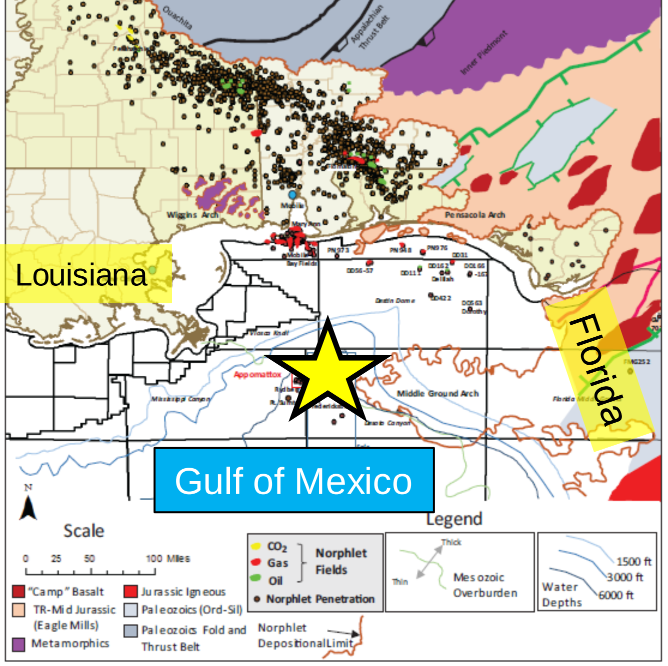


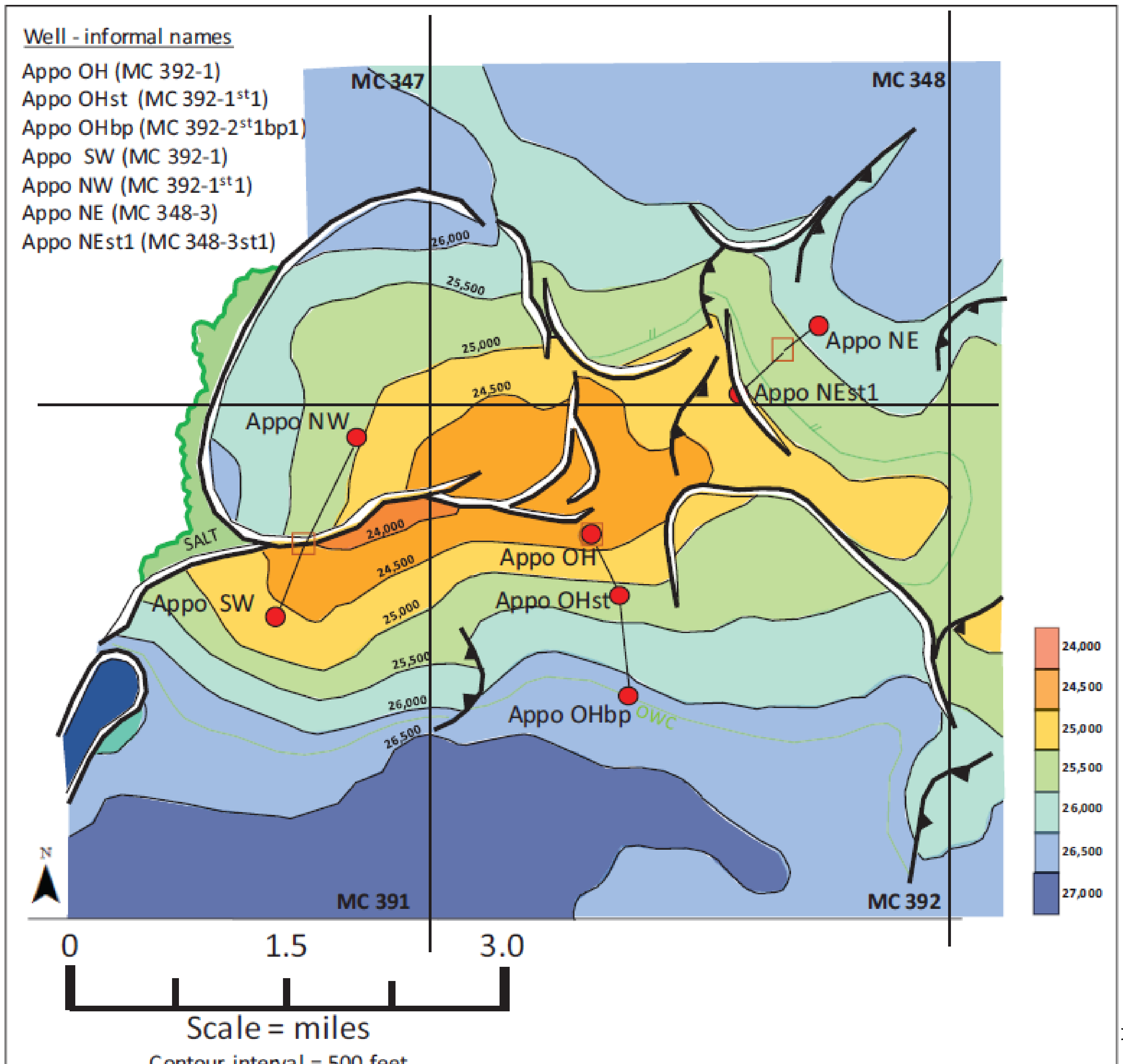
Super deep Ordovician oil-6000-8000 meters-Halahatang oil field, Tarim Basin, China: 2.2 BBOE, 17-45 API-2010 Discovery, Tarim Oil and Gas Company



- **7000-8000 meter oil**
- Combination trap-karsted carbonate reservoirs
- High pressure
  - 10,878-12,238 Psi
- Moderate to high temperatures
  - 140º-172ºC
  - Cold geothermal gradient (22º C/Km)
- Mature oil-carbonate marine source rock (Cambrian)
- High salinity water
- Oil density
  - .8-.9 g/cm^3
  - **(17-45 API)**

Appomattox-2009-Oil and Gas- 650 MMBOE



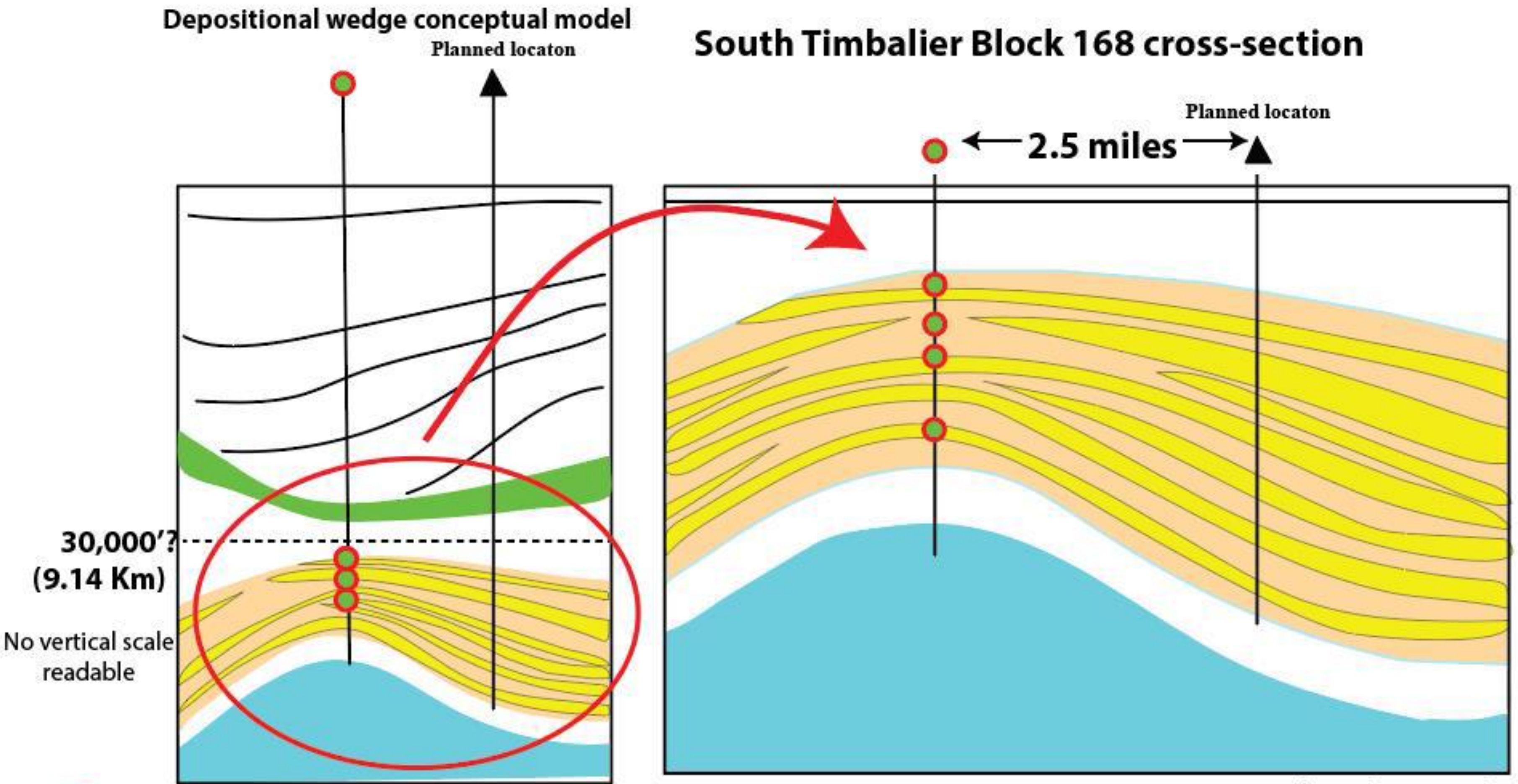


- Deep water:
  - 2096 m (6876 ft)
  - Sub-salt structural trap
- Reservoir depth
  - Jurassic Norphlet Aeolian
    - 162 m (530') oil
  - 24,000-25000 ft
    - (7314-7619 m)
  - Below mudline
    - ***(17,124-18,124 ft below mudline)***
    - ***5219-5523 m below mudline)***
  - Porosity preservation from chlorite rim cements

digm Shifts

2008 Blackbeard well

South Timbailier Depositional Wedge Model and Discovery
Estimated 1 BBOE, shallow water, sub-salt



Oil or gas-condensate

Blackbeard well 2008
Oil or Cond pays
TD 32,997 FT
10596 m

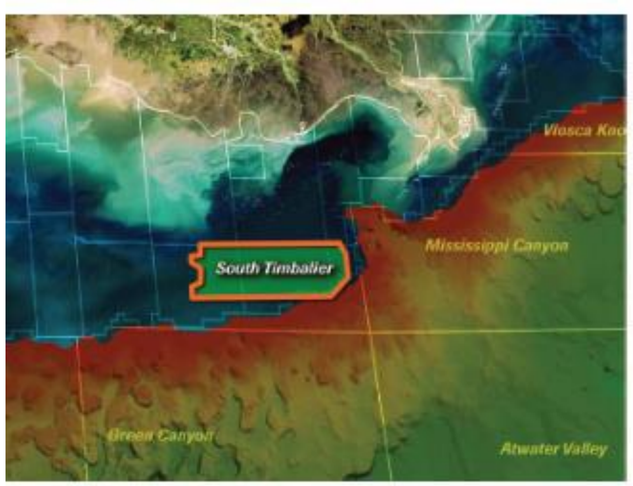
Abandoned to test in high pressure setting
As of 2021, results unknown

McMoran-Freeport

High Pressure 25,000 PSI
High quality deep water
Oligocene Frio Sandstones
and Miocene Rob-L sandstones

Flat rock area nearby:
14,800-17200 Ft
(4500-5242 m)
Good porosity
gross production
280 MMCGFD
(also geo-pressured)

- Gulf of Mexico sub-salt generalizations
- Cool geothermal gradient
- High pressure
- Still good phi/k at 9+ kilometers (30,000') below mudline



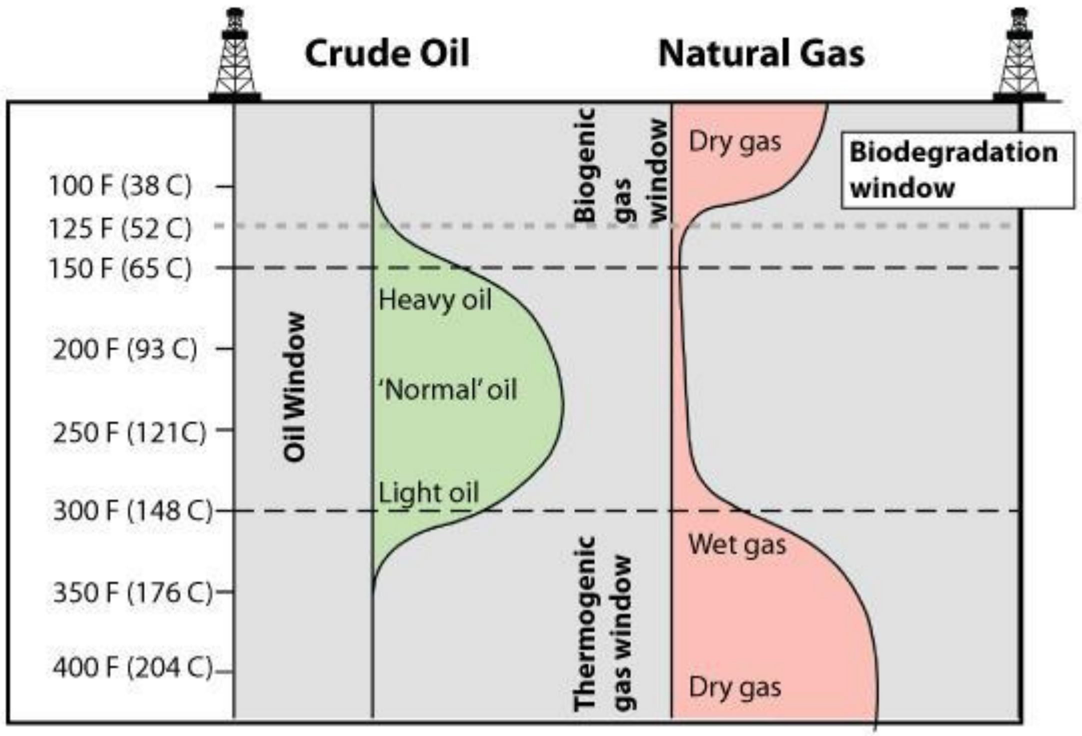
Location image from:
https://www.slb.com/reservoir-characterization/seismic/multiclient-data-library/gulf-of-mexico-south-timbalier

Modified by J. Dolson
9/25/2021 from
OGJ 2008 article

https://www.ogj.com/drilling-production/article/17218200/ultradeep-shelf-well-logs-four-indicated-pays-in-miocene

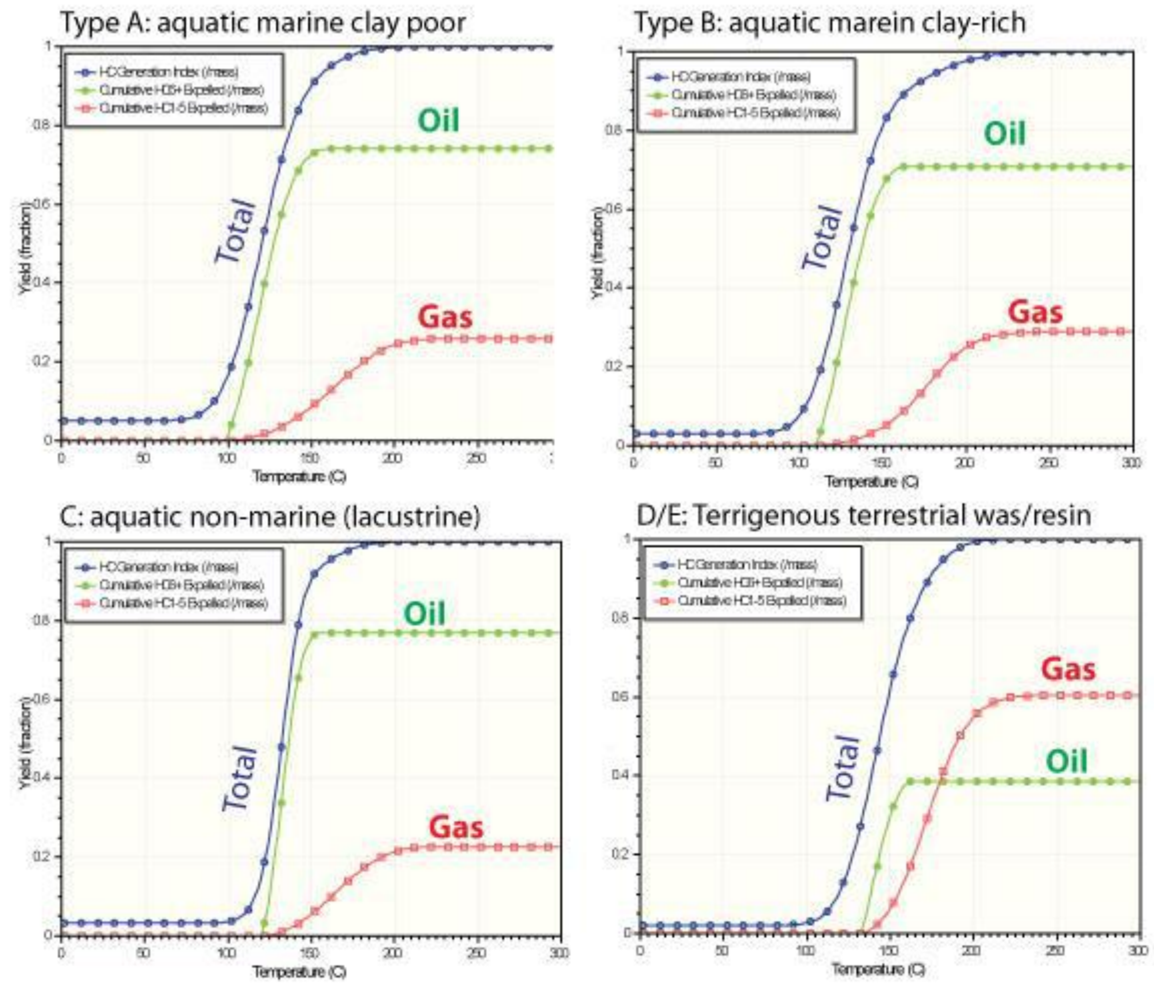
Liquids at great depth: re-think things

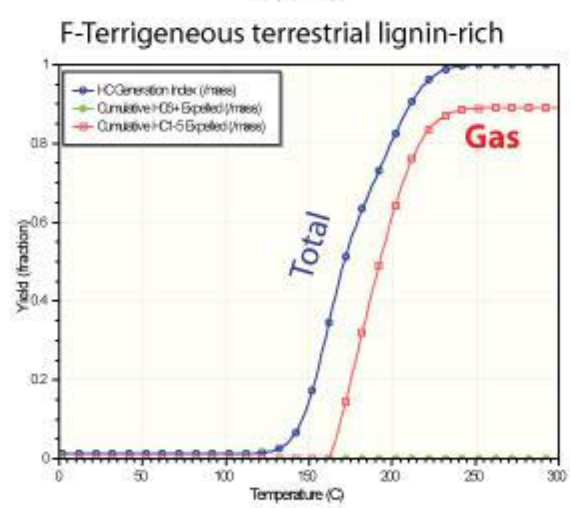
Generalized oil and gas windows as a function of temperature



- Kinetics of source rocks
- Pressure
- PVT properties

Variable kinetics of source rocks by type and temperature



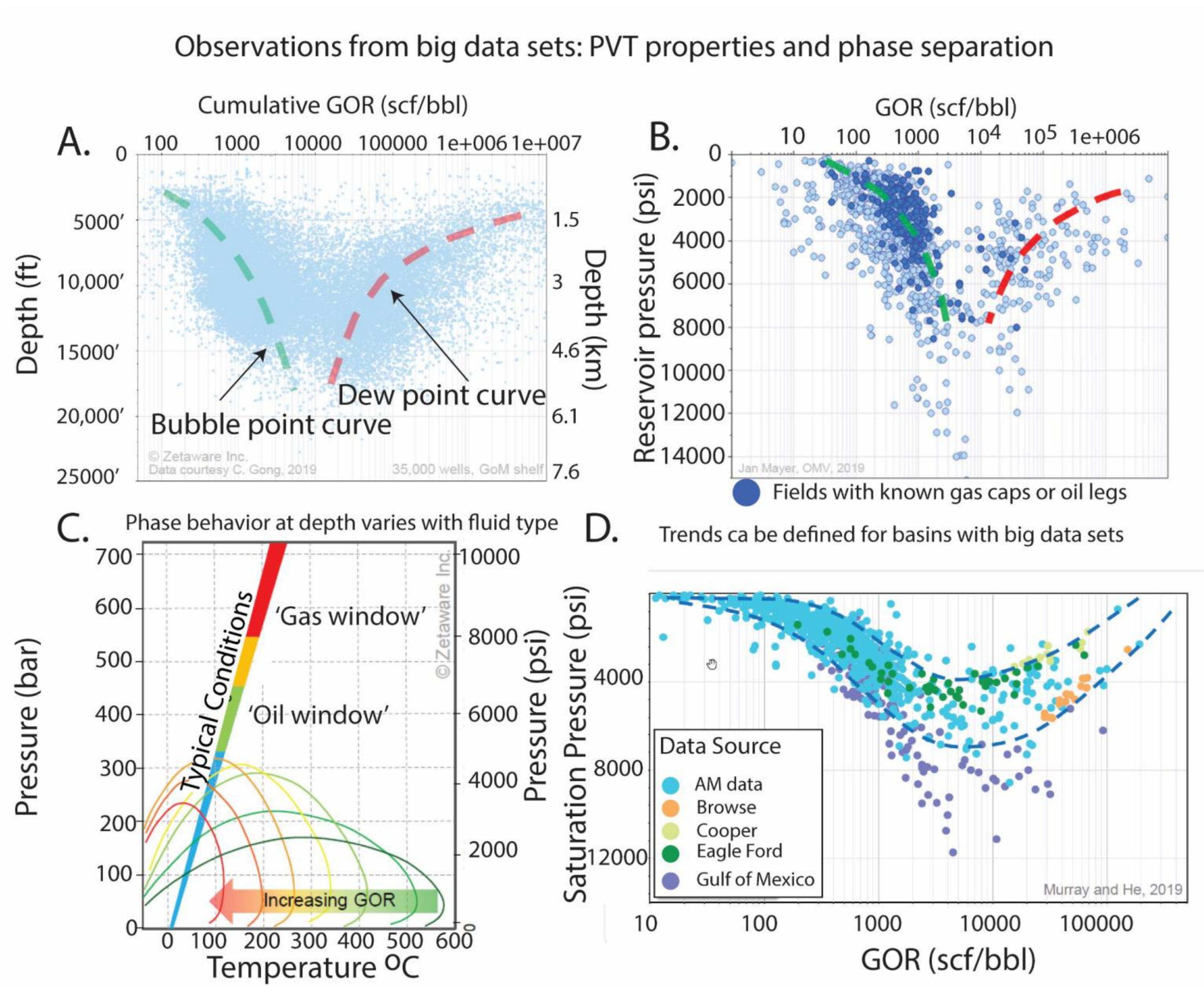


Note: these are rough standards following the BP model of Pepper and Corvi (1995).

They can also be modeled as mixed combination and against Ro, TR or many other variables.

Where possible, obtain your own kinetics through direct measurement of source rocks.

Global datasets: GOR vs depth, pressure

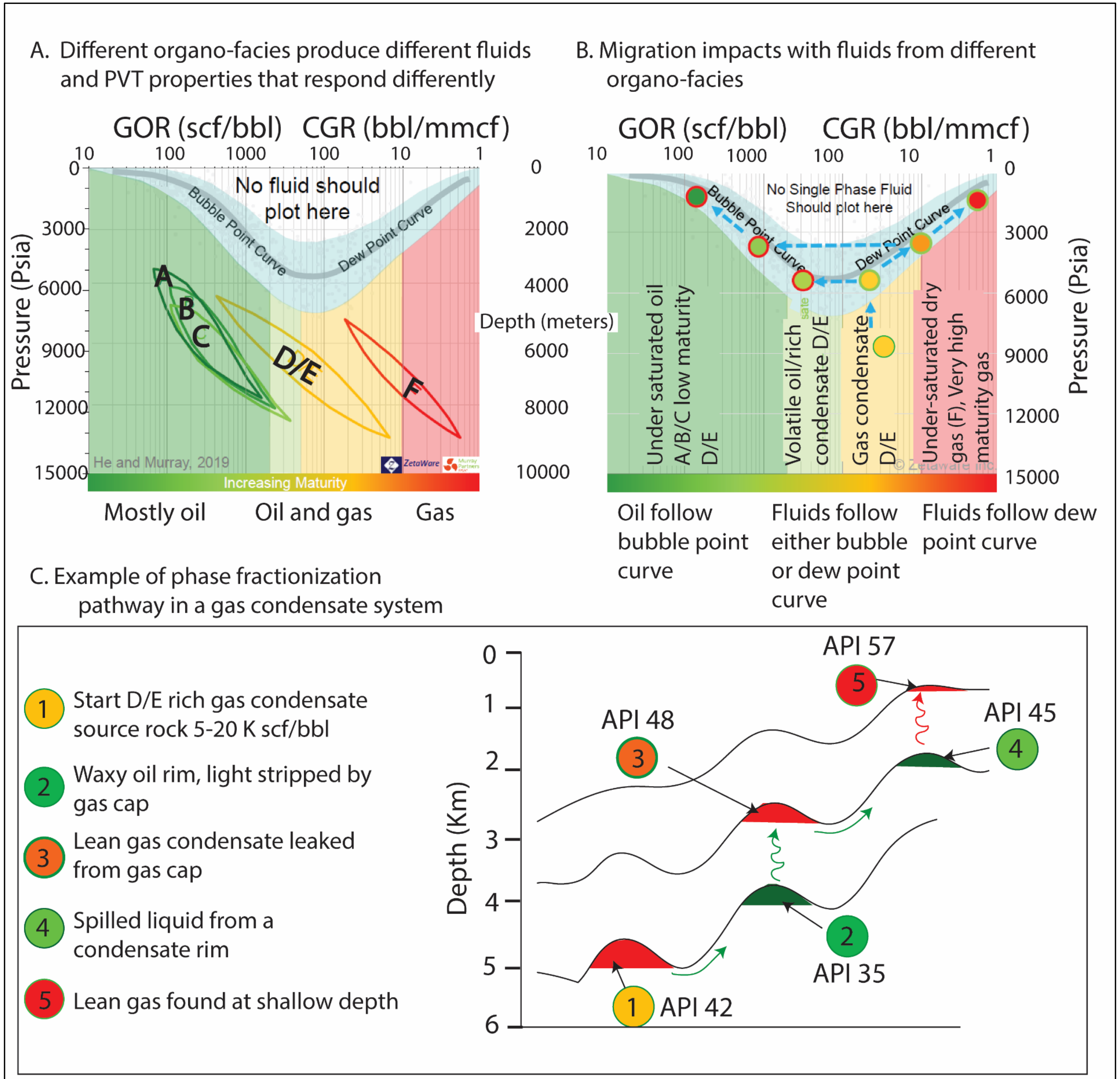


High pressure at depth helps preserve initial oil and gas generated by source rock.

The source rock may be 'spent', but the liquids expelled may not 'crack' to gas.

As they migration, phase changes occur either to gassier or heavier oil, so gas fields can lie over deep oil fields from the same source rocks.

Example of phase changes with migration



What is in the deepest basins may be quite different from the fluids after vertical migration and phase changes

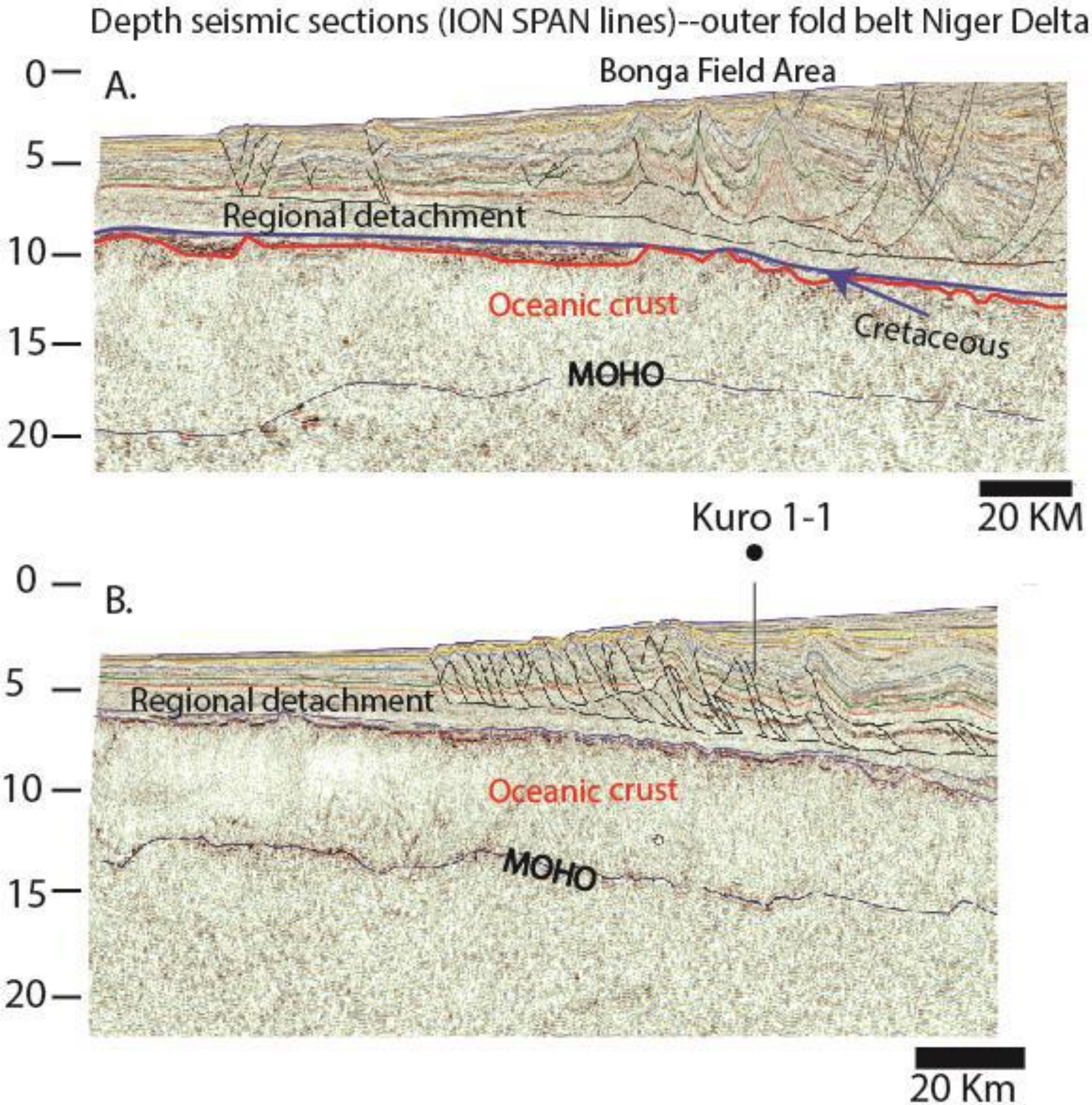
Field	Long	Lat	Year	Country	Type	Class	MMBOE	Comment
Mad Dog	-90.2	27.28	1998	United States	Oil	Giant	500	Hydrodynamic
Britannia	0.83	58.08	1975	United Kingdom	Gas and Condensate	Giant	668.93	Hydrodynamic
El Temsah	32.5	32	1977	Egypt	Gas and Condensate	Giant	916.67	Hydrodynamic
Ormen-Lange	5.34	63.54	1997	Norway	Gas	Giant	1833.33	Hydrodynamic
Azeri	51.28	40.05	1987	Azerbaijan	Oil	Giant	1284.67	Hydrodynamic
Guneshli	51.1	40.17	1979	Azerbaijan	Oil	Giant	762.07	Hydrodynamic
Shah Deniz	50.42	39.85	1999	Azerbaijan	Gas and Condensate	Giant	4483.33	Hydrodynamic
MJ-1	82.85	16.53	2014	India	Gas and Condensate	Large-significant	223	Hydrodynamic
Yakaar-1	-18.22	15.16	2016	Senegal	Gas and Condensate	Giant	2950	Oceanic crust
Agulha 1	41.21	-11.37	2013	Mozambique	Gas and Condensate	Giant	1000	Oceanic crust
Coral 1	41.17	-11.15	2012	Mozambique	Gas	Giant	1848	Oceanic crust
Lavani 1	40.44	-9.38	2012	Tanzania	Gas	Giant	672	Oceanic crust
Zafarani 1	40.44	-9.24	2012	Tanzania	Gas	Giant	697	Oceanic crust
Tangawizi 1	40.5	-9.32	2013	Tanzania	Gas	Giant	636	Oceanic crust
UD-1	82.14	15.12	2007	India	Oil and Gas	Large-significant	333	Oceanic crust
Mronge 1	40.48	-9.07	2013	Tanzania	Gas	Large-significant	400	Oceanic crust
Ahmeyim	-17.62	16.13	2015	Mauritania	Gas	Giant	2796	Oceanic crust
Orca-1	-17.55	16.51	2019	Mauritania	Gas	Giant	1668	Oceanic crust
BirAllah	-17.551	16.608	2015	Mauritania	Gas	Giant	616	Oceanic crust
Bonga N-1	4.55	4.64	2004	Nigeria	Oil and Gas	Giant	610	Thin transitional crust
Bonga Southwest	4.53	4.46	2001	Nigeria	Oil and Gas	Giant	921	Thin transitional crust
Bonga	4.36	4.33	1996	Nigeria	Oil	Giant	1200	Thin transitional crust
Agbami	5.56	3.46	1998	Nigeria	Oil and Gas	Giant	1059.44	Thin transitional crust
Ikija	5.37	3.42	2000	Nigeria	Gas	Giant	500	Thin transitional crust

Upward hydrodynamic flow tilted contacts

2 more paradigm shifts

Oceanic crust or thinned continental

Pushing the envelope beyond continental crust with giant traps

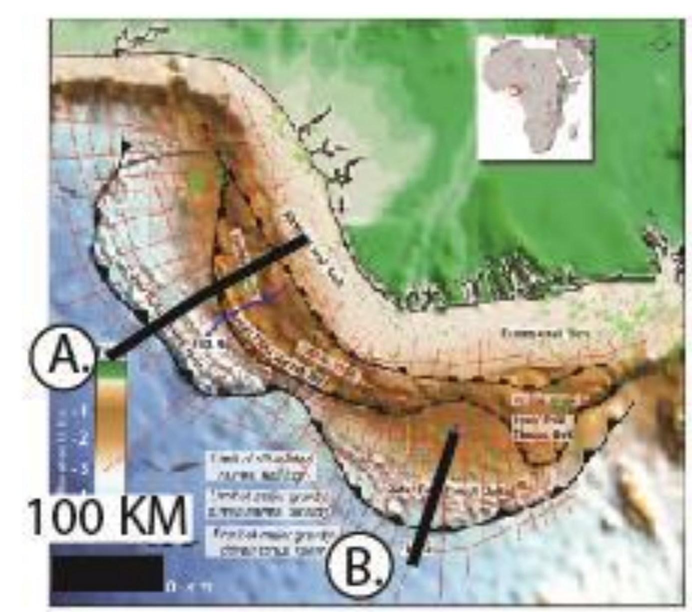


Niger Delta fields on thin transitional or oceanic crust:

- Bong North-1 (2004)
- Bonga Southwest (2001)
- Bonga (1996)
- Agbami (1998)
- Ikija (2000)

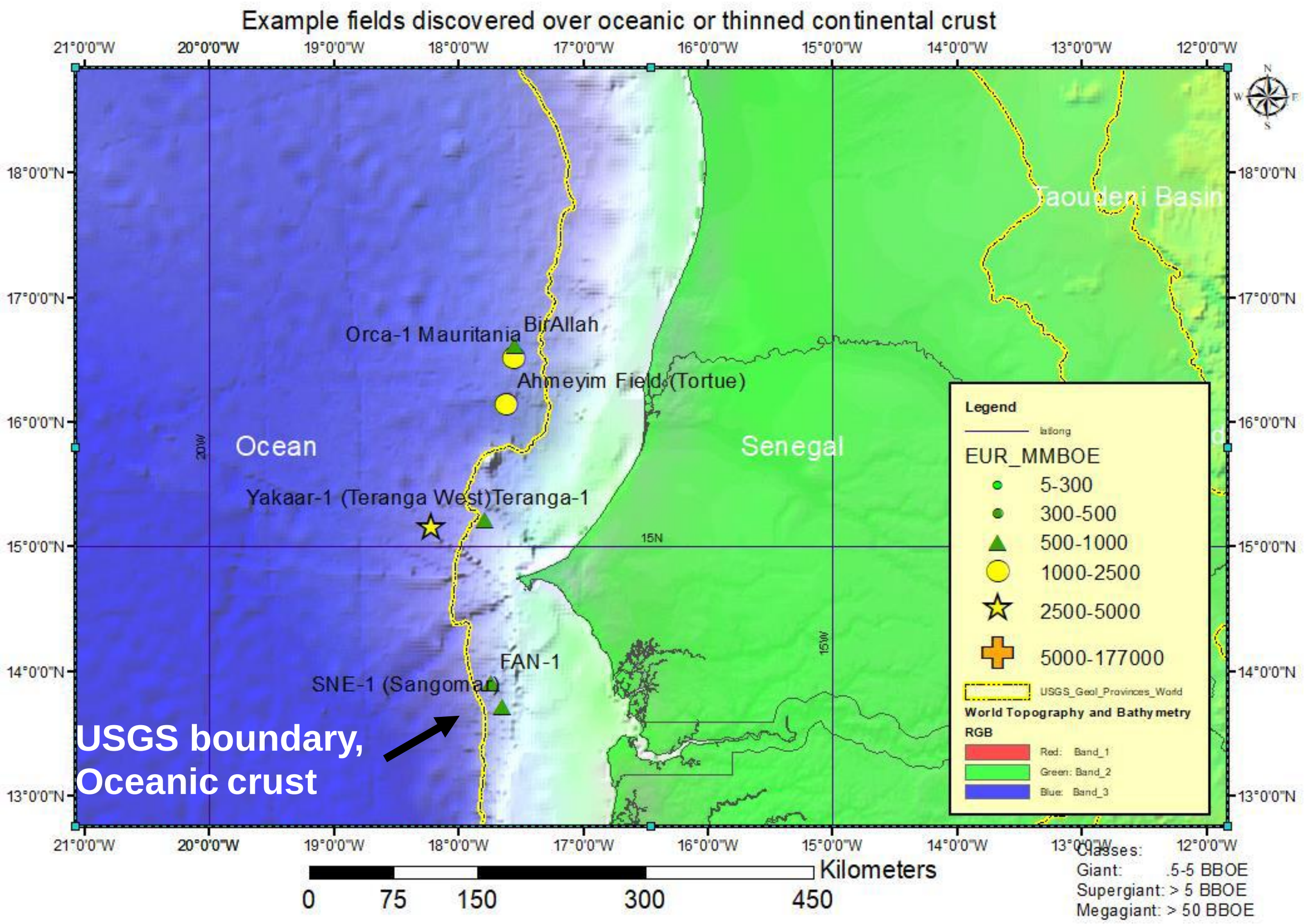
Others on or near oceanic crust

- UD-1 (India, 2007)
- Orca, Ahmeyin (Mauritania, 2019, 2015
- Coral, Agulha (Mozambique, 2012,2013)
- Yakaar (Senegal, 2016
- Mronge, Tangawizi, Zafarani, Levani (Tanzania, 2012, 2013)



Map from Bellingham, et al., 2014, GeoExpro

Senegal offshore- Huge new as gas/condensate fields: oceanic or thin continental crust



2105 Discovery, opens up 100 + TCF (Kosmos Energy)

- 11.28 TCF , 226 MMBC at Tortue
- Cenomanian-Albian sandstones
- Source rock unknown
- 2776 meters water depth
- Reservoirs at 5200 meters, 2424 meters below mudline (shallow burial)

Images from McGuinness et al., 2021, AAPG Memoir 125

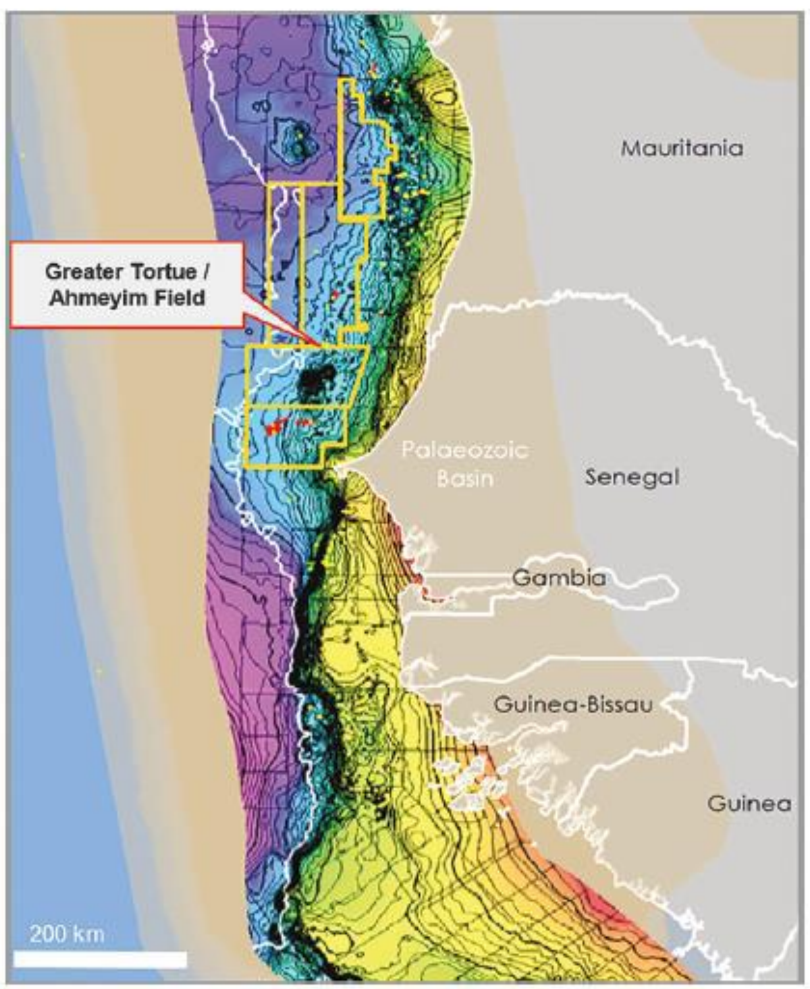
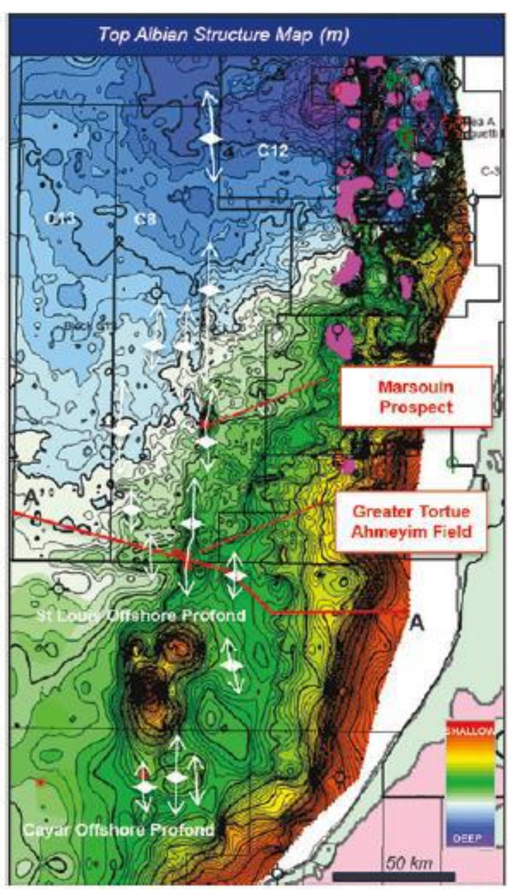
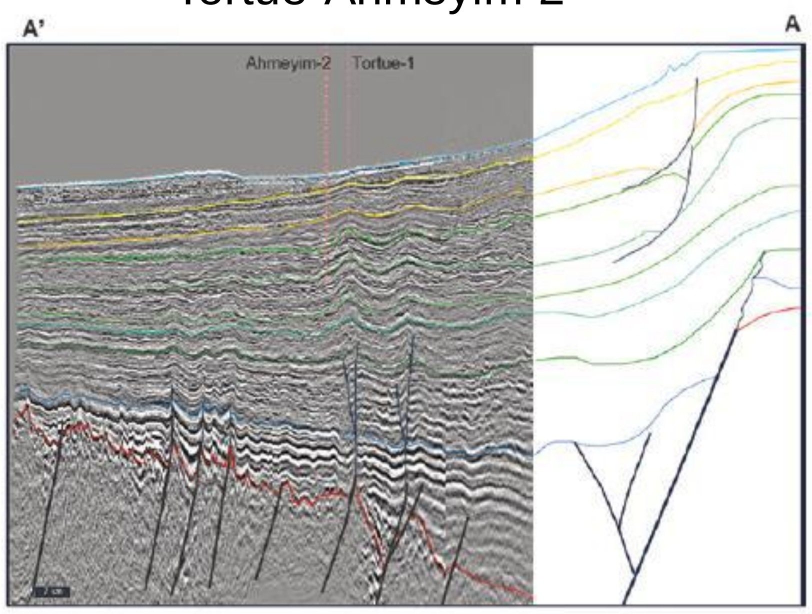


Figure 1. Geographic location the Mauritania-Senegal-Guine Bissau–Conakry Basin (MSGB Basin) along West Africa. Simplified offshore structure map showing Kosmos Energy's acr age position on entry prior to the discovery of the Greater Tortue/Ahmeyim Field.

ı: Giant Fiel



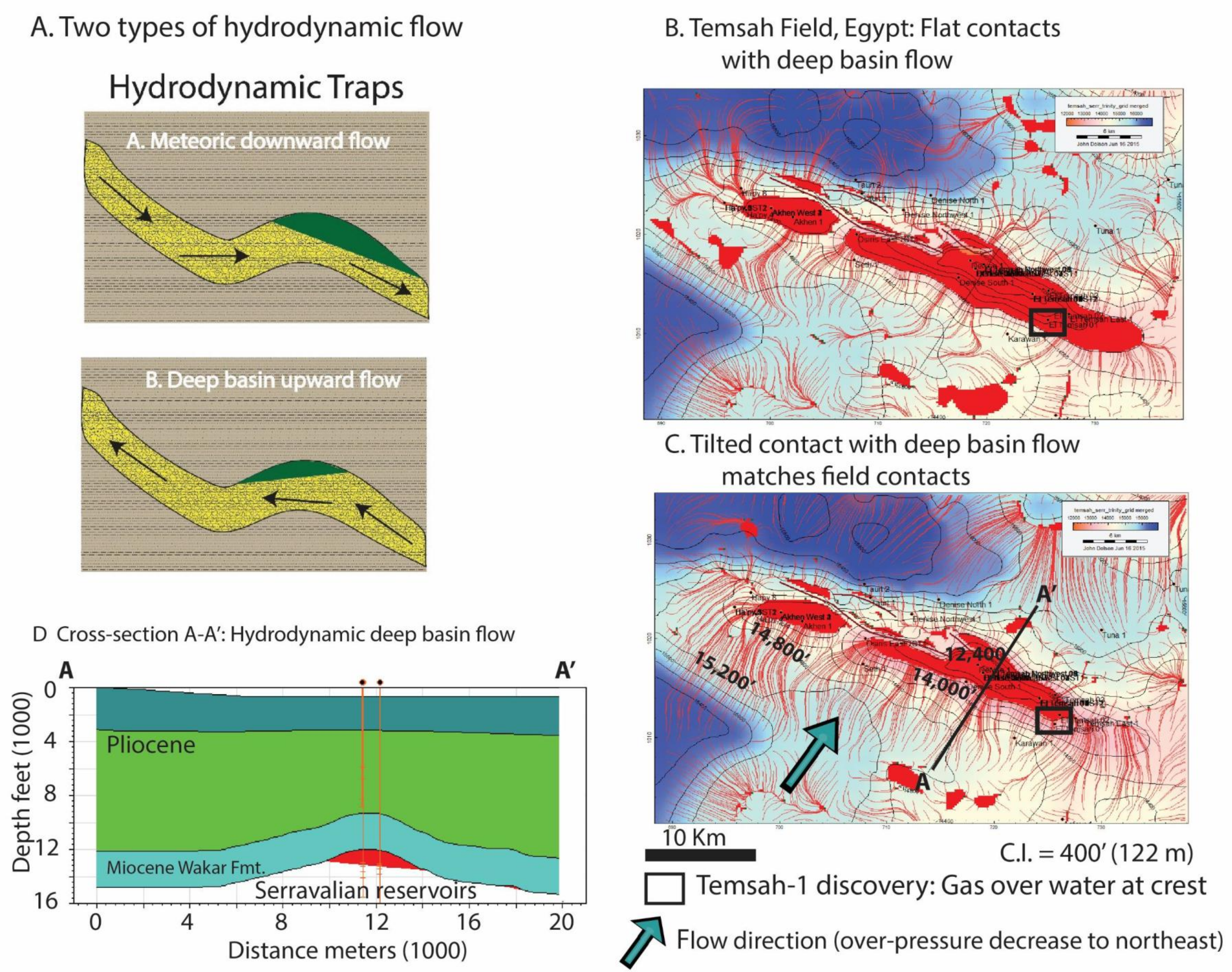
Tortue-Ahmeyim-2



Thinned continental crust within USGS oceanic crust boundary

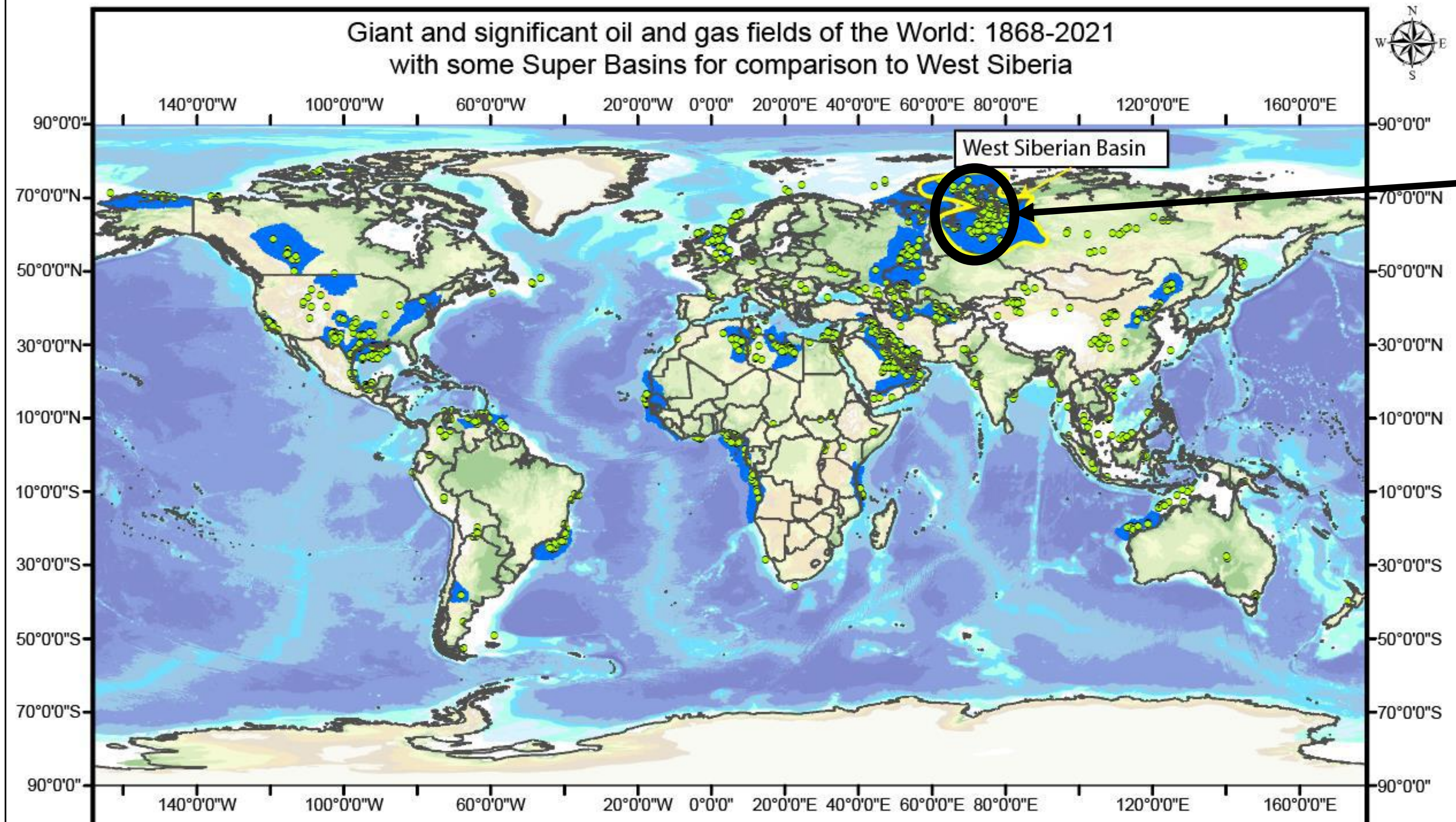
Figure 4. The deep-water basin contains a north–south trending anticlinorium comprised of en echelon periclinal anticlines formed during episodic deformation from the Late Cretaceous to Middle Miocene. The anticlinorium results from transpression along faults rooted in the crust. (Note: Tortue-1 was renamed Ahmeyim-1.)

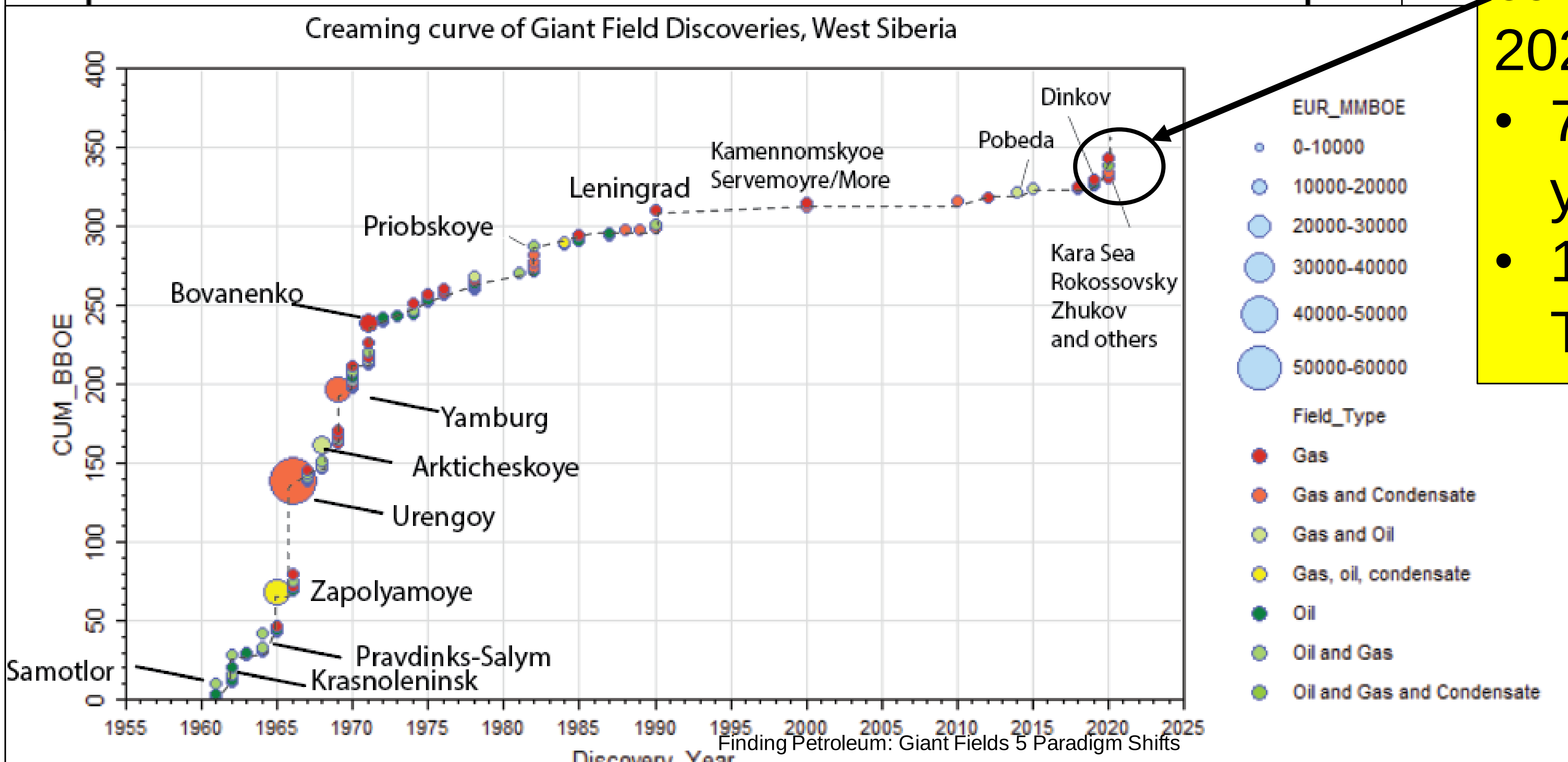
Increasing recognition of deep, over-pressured basin hydrodynamic tilting (literature review since 2000)—example of 25 years to recognition of tilt-Temsah-Field, Egypt-this may turn out to be the norm in deep plays



Where next?

- Harsher, more difficult new area access or imaging
  - Kara Sea, Arctic
  - Politically unstable countries
  - Sub-volcanics
  - Difficult sub-salt
- Drill deeper into older basins below proven systems
  - Test the deepest petroleum system
  - Question paradigms on source, charge migration
    - Geochemical oil and rock typing to unlock new plays
    - Fluid Inclusion Stratigraphy
  - Old planet, lots of undrilled rock out there
    - Rich Neoproterozoic source rocks globally—are they all tested?





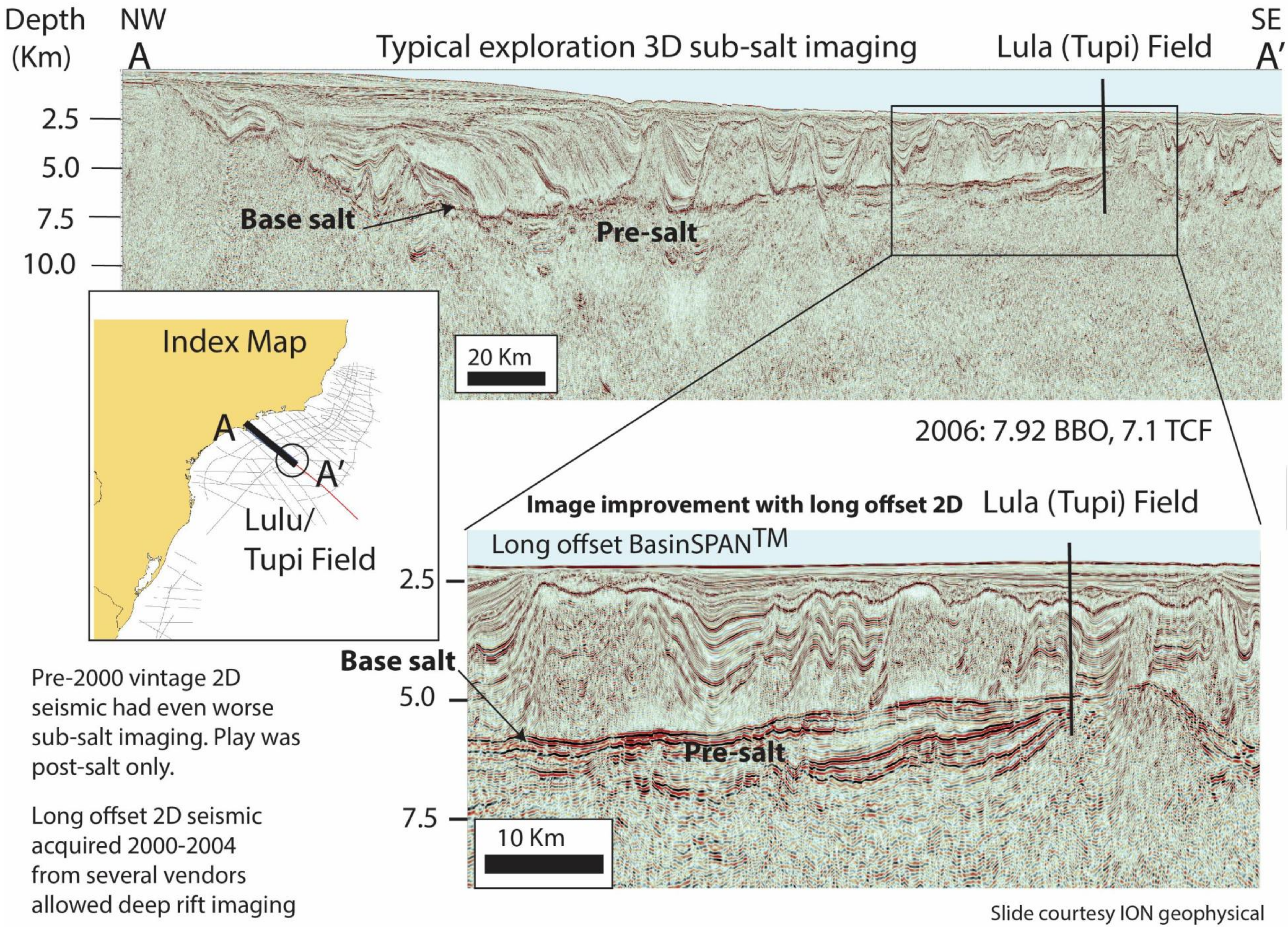
New Access, old plays (structures)- Arctic potential huge

Partially ice-bound Kara Sea, offshore West Siberian Basin

Giant fields creaming curve broken 2019-2021

- 7 new giants in two years
- 17.8 BBOE (107 TCF)

Increasingly better seismic imaging—looking deeper, older stratigraphy: old play was post-salt! Big play pre-salt!



Look deeper, older stratigraphy-Sichuan Basin Neoproterozoic, China example

DU Jinhu et al. / Petroleum Exploration and Development, 2014, 41(3): 294–305

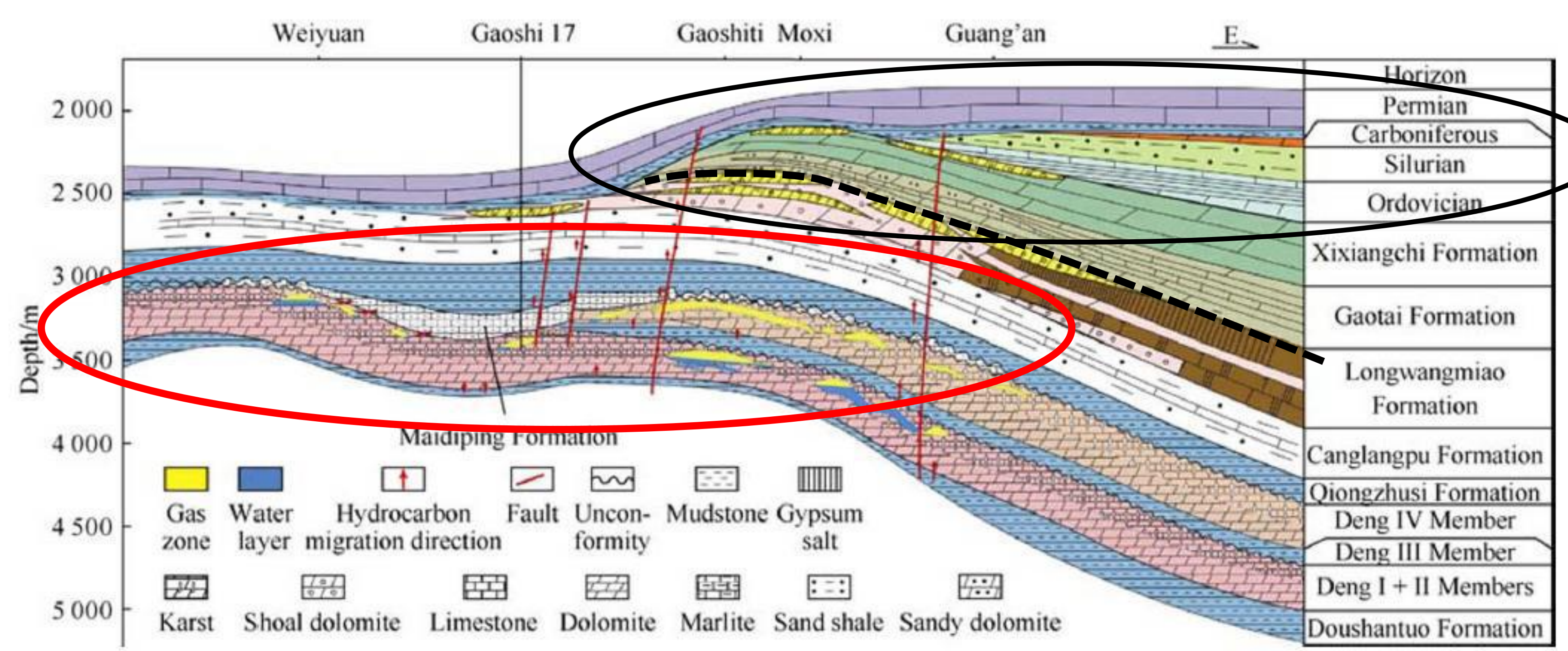


Fig. 9 Forming pattern of Sinian-Cambrian gas reservoirs in central Sichuan paleohigh

Shallow play: Upper Cambrian

Deep play: Neoproterozoic (Sinian) and Lower Cambrian

Shallow play closure: Longwangmiao Formation—hidden deep traps not matching structure

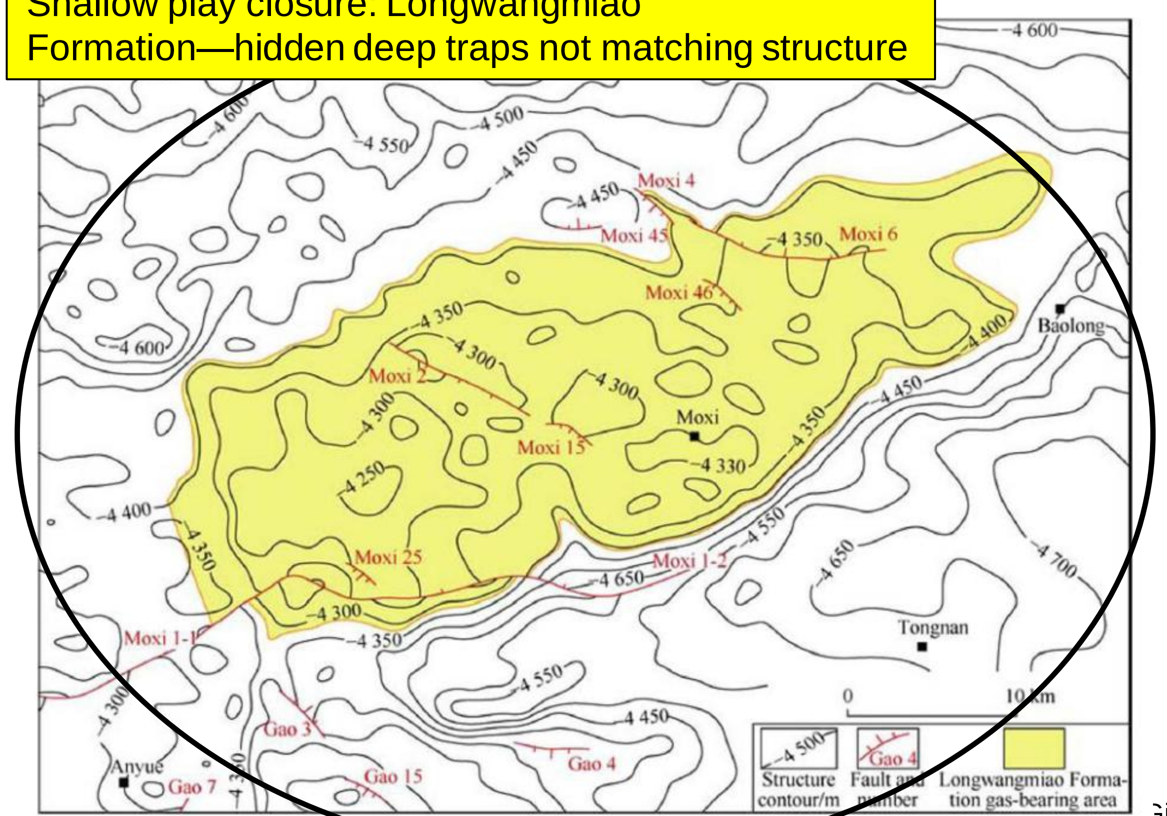
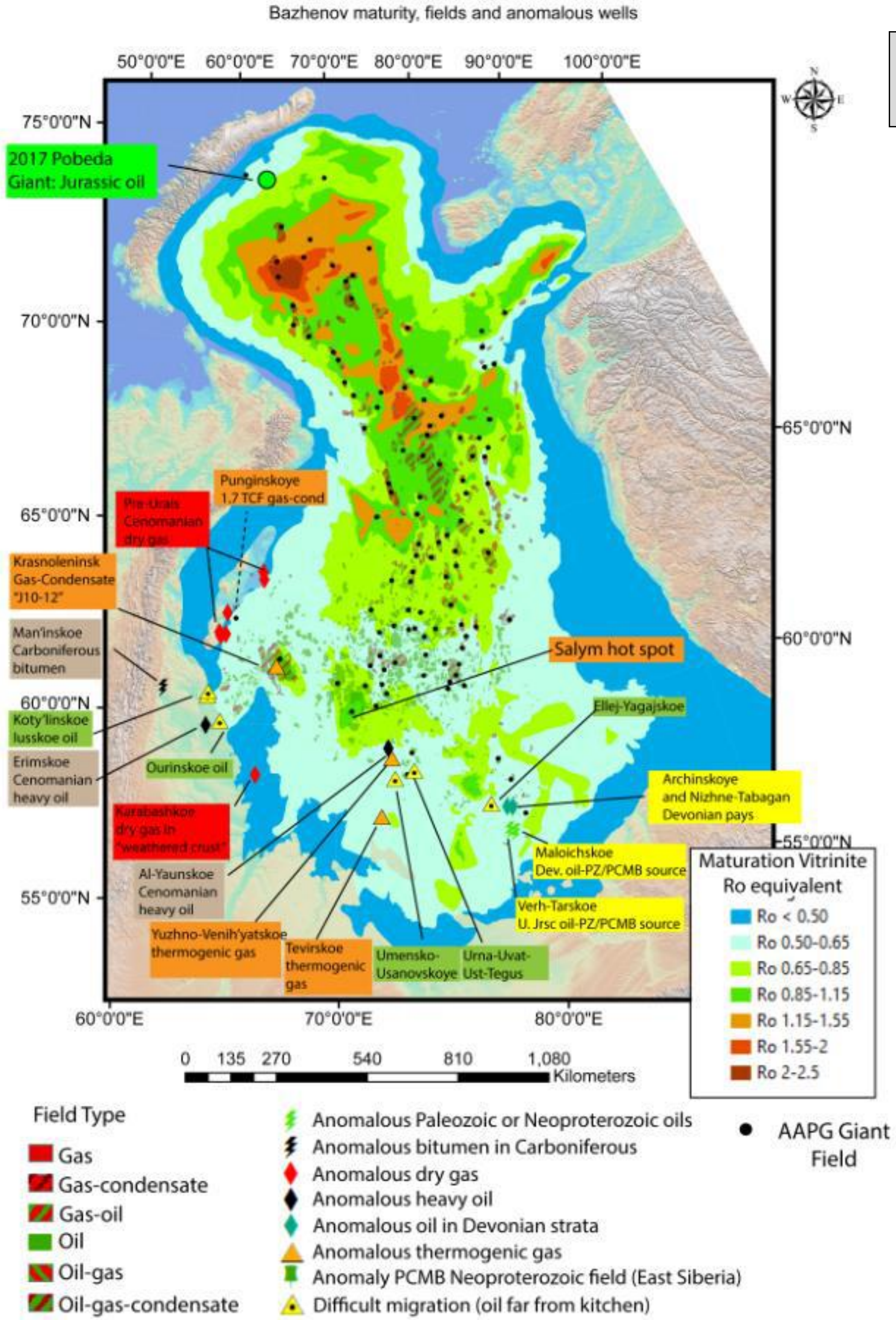


Fig. 3 Plan view of Longwangmiao Formation gas-bearing area in Moxi block of central Sichuan Basin

Old field re-vitalized:

- Gas pools known since 1970's
- ***2011 Realization deeper pools***
  - Neoproterozoic/Lower Cambrian
  - Trillion m^3 gas (35 TCF)
  - High pressure, high temperature
    - 76 Mpa pressure (11023 psi) at -4324 m (14147 ft)-.78 psi/ft)
    - 141.4 ^{o}C
  - Lowest gas -4459 M, 100 m below closure, no water leg defined

Question paradigms

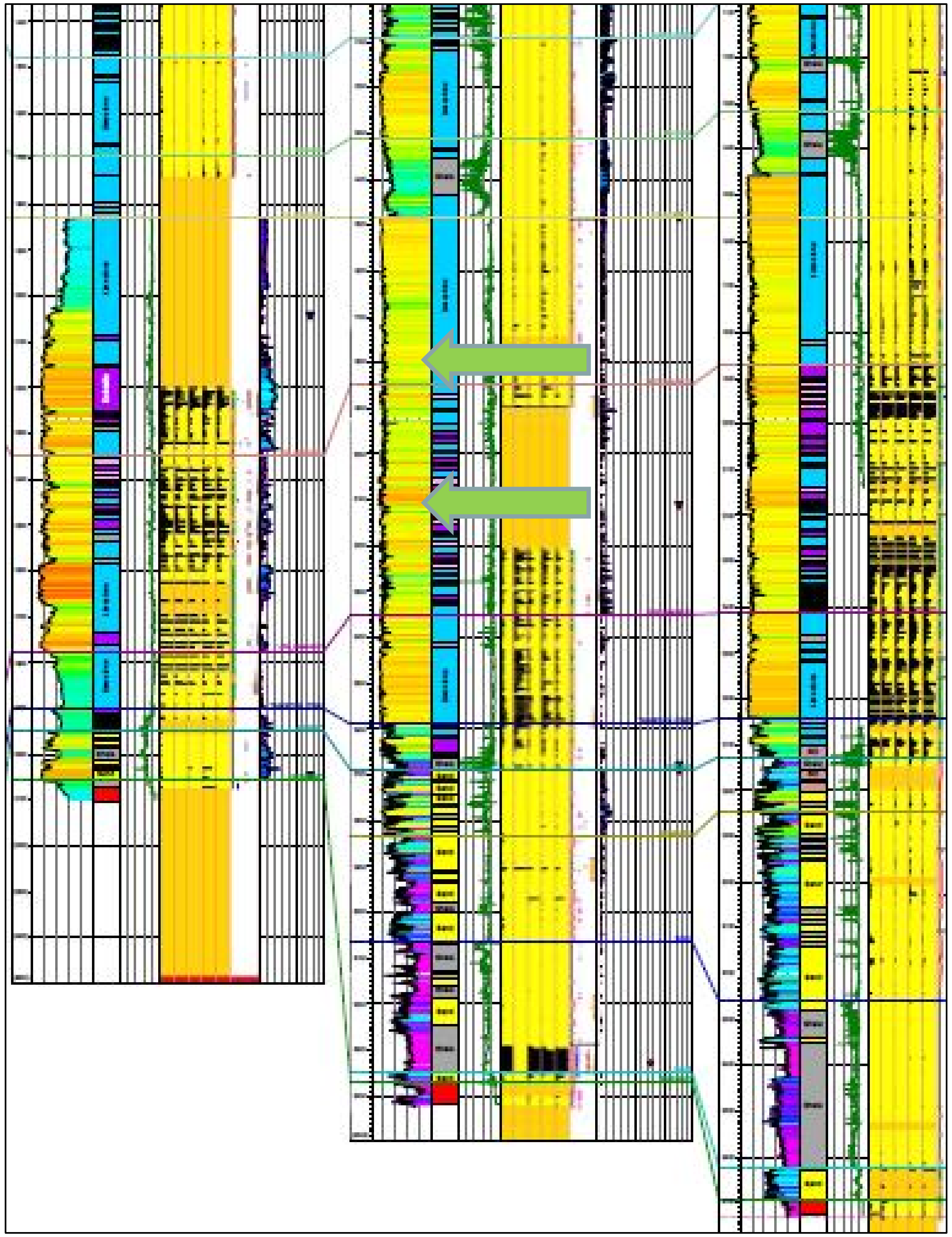


- Geochemical anomaly mapping, West Siberia
  - Jurassic/Cretaceous petroleum system but…
    - Bazhenov (Jurassic) maturation map, or Lower Jurassic source rocks can't explain all anomalies easily
  - Neoproterozoic source proven in SE corner
  - Thermogenic gas well beyond gas or oil windows in Mesozoic systems
- Ask the right questions
- Be a skeptic

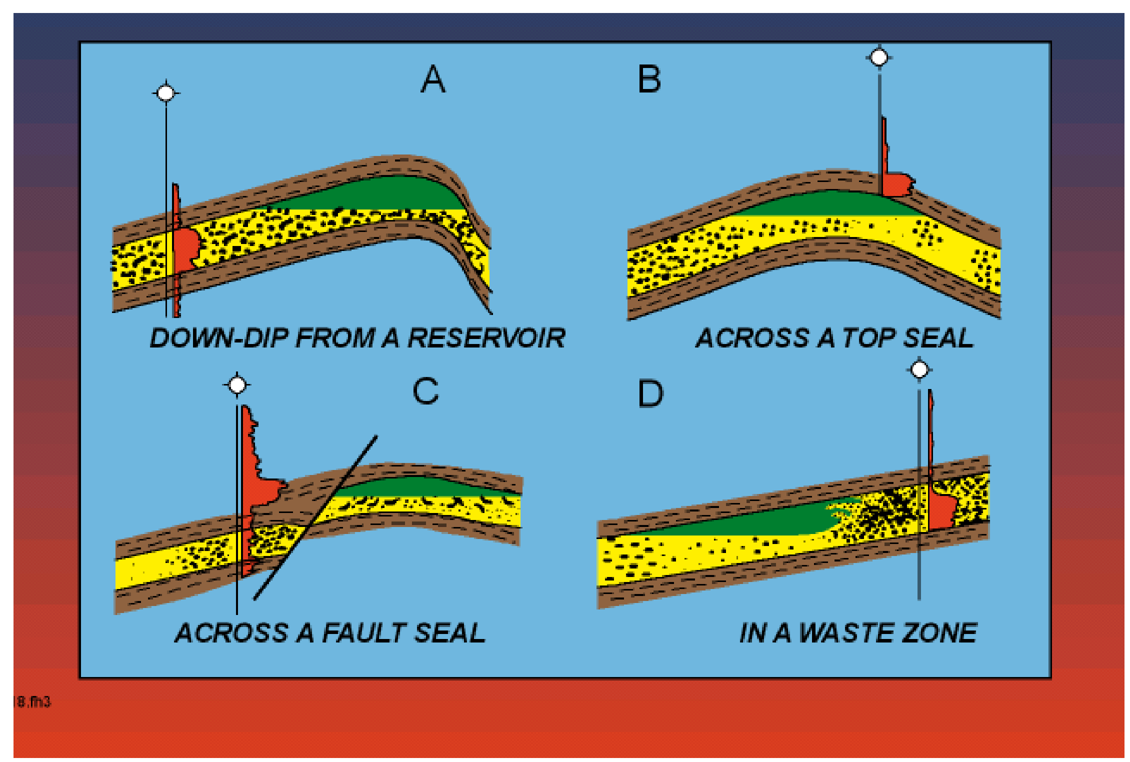
Fluid inclusion stratigraphy: cheap, fast, new look, old basins

150 Km (90 Mi)-Migration pathway-these wells:
800 Km pathway proven regionally

Migration pathway in regional carbonate zone. Orange 'blank' zones are intervals of no samples.



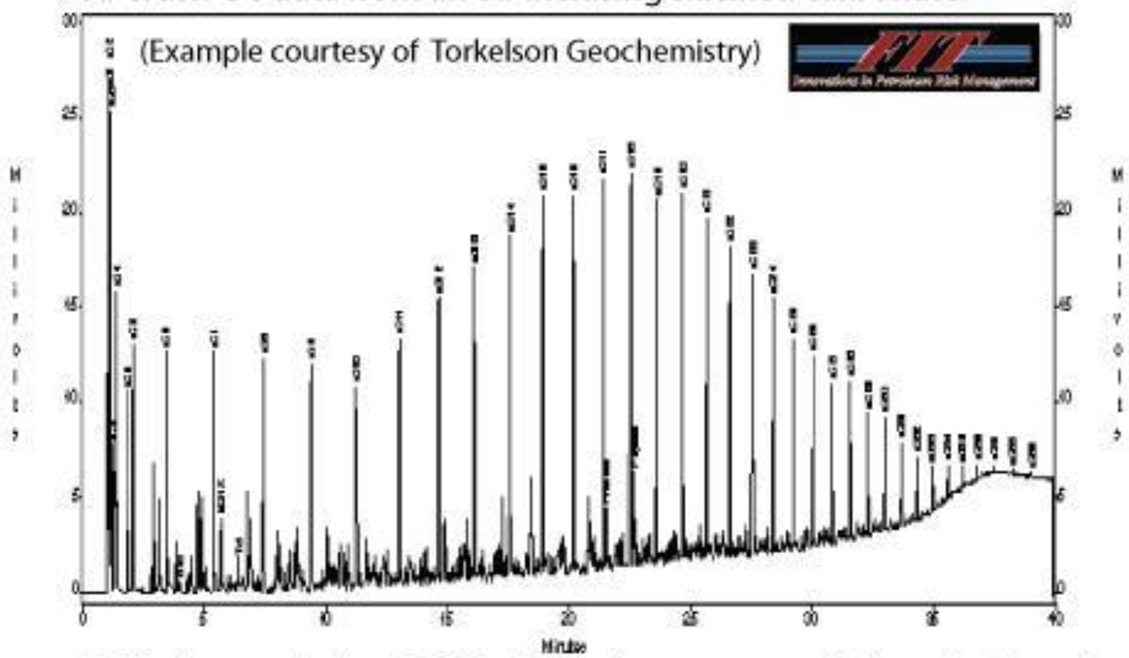
- Other data
  - Paleo water salinity
  - Temperature of emplacement
  - Api gravity
  - GCMS
  - Seal identification
  - Source rock identification, maturity
  - Integration to burial models



Geochemical data used to tie oil to source rocks—this can come from FIS data!

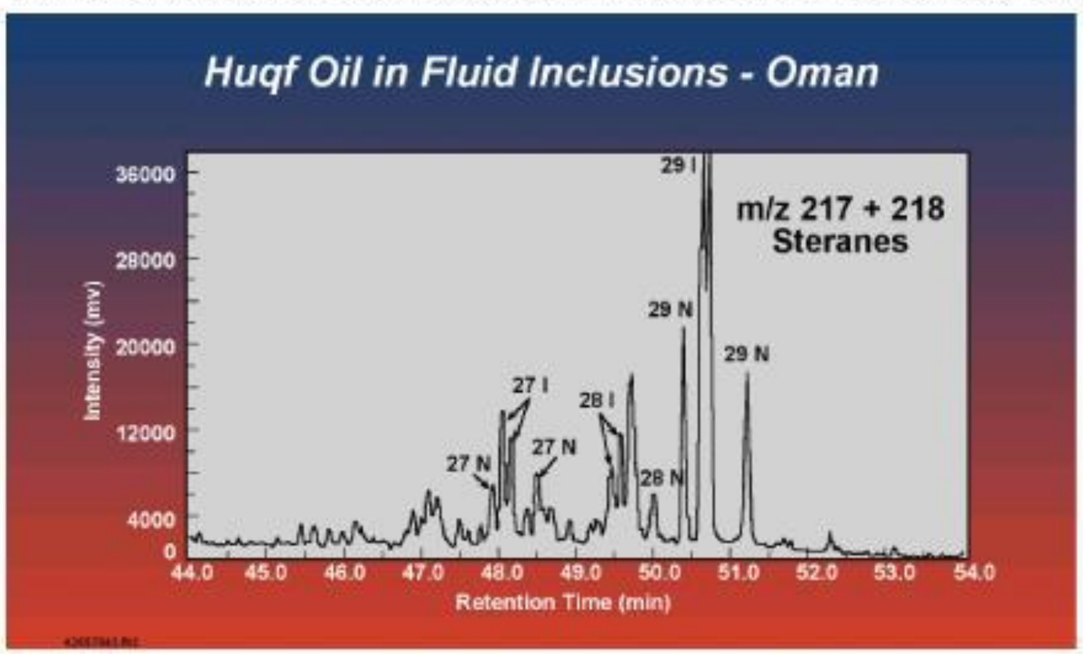
Additional geochemical information that can be gleaned from fluid inclusions

A. Crush GC data from an oil-inclusing silicified carbonate.



Utility of these data:
* Oil families
* Gross maturity of the oil
* Water washing or biodegradation

B. Higher resolution GCSM data, solvent extract, Paleozoic of southern China



Utility of these data:
* Oil to source rock ties for migration studies
* This kind of information provides the link back to migration modeling

Why wouldn't anyone want information like this?

Unlocking complex migration pathways!

Oil geochemistry data is essential to validate migration and burial models.

Analogs and anomalies count! You can't have enough analogs in your 'tool kit'!

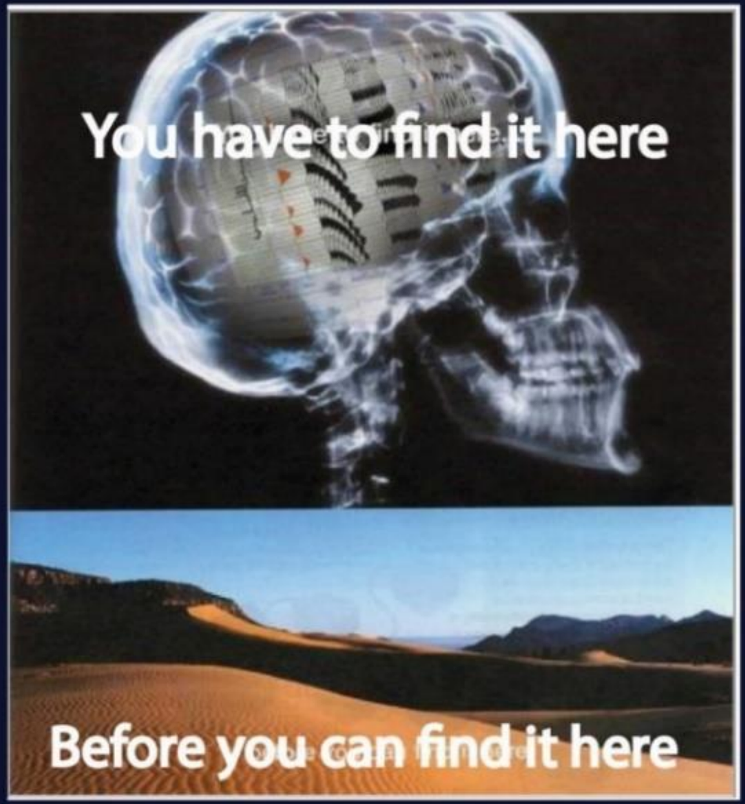
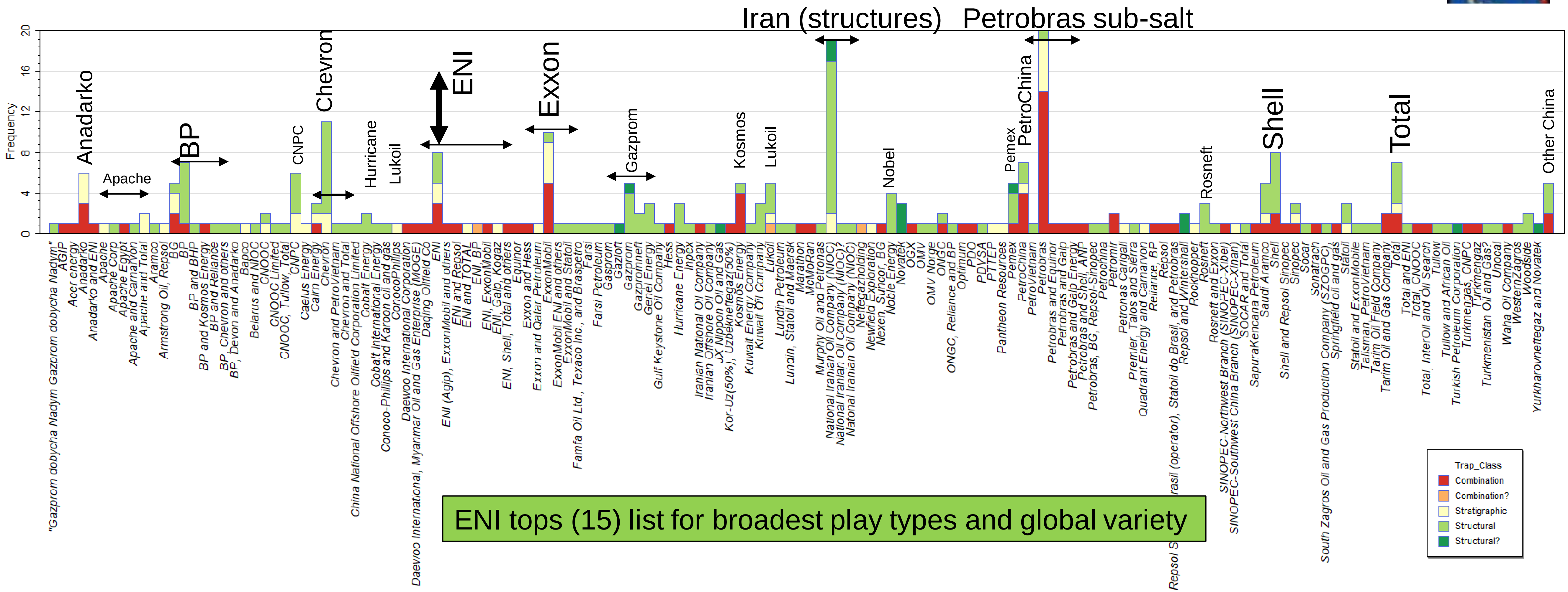


Image and quote courtesy Stuart Burley

BACKUP

Who were the big giant field finders, last 20 years?



But that is only part of the story! Who were some of the 'new play makers?"

- ENI: Zohr, other global giants, variety of plays (15 total)
- Kosmos: Cretaceous turbidites African margin
- Exxon/Mobil: Guyana offshore
- Cove Energy: Mozambique Tertiary-Cretaceous deep water
- PetroChina, other Chinese companies: Deep drilling, carbonate giants
- Tullow-East Africa rift, Africa turbidites
- Rockhopper (Falklands)
- Nexen, Suncor, BG (Buzzard, North Sea)
- Hurricane Energy: Giant fractured basement, Faeroes-Shetland-Orkney Basin
- Armstrong energy (North Slope, Alaska)

2012: Zafarani-5.2 TCF, Tangawizi 4.8 TCF GIP-offshore Tanzania

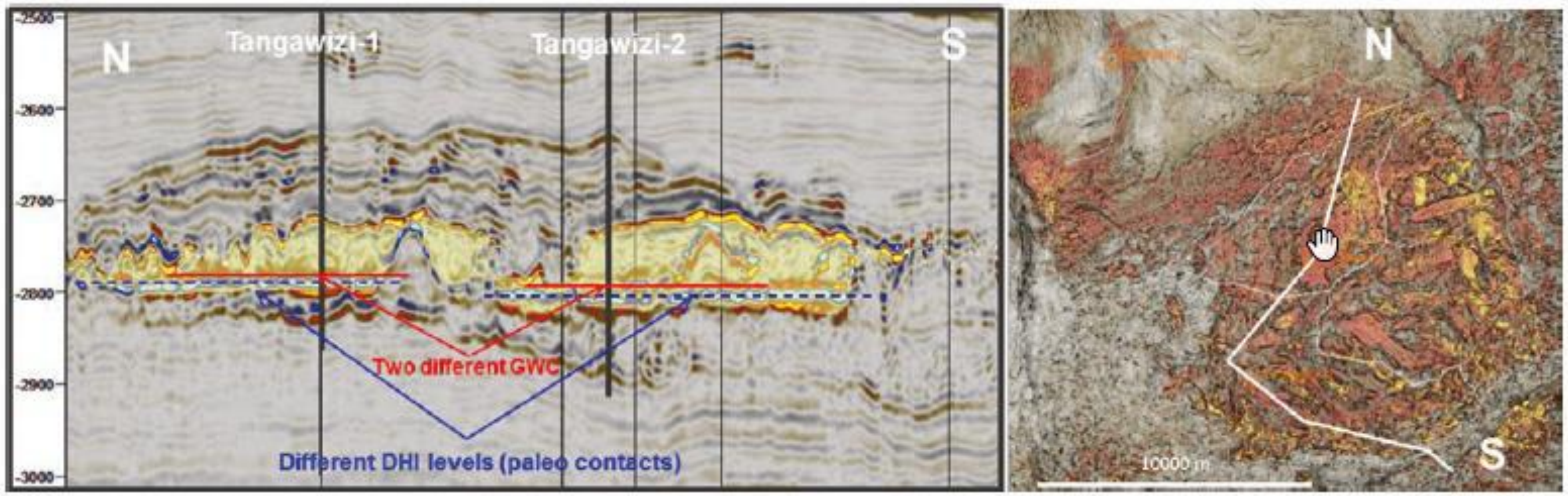


Figure 27. Random line through the Tangawizi reservoir indicating the outline of sand bodies (left) between top and base gas. Note differences between GWCs and RGWCs. The figure to the right shows a variance map clearly shows the outlines of sand bodies with varying orientations.

Tangawizi giant tilted contact or perched water

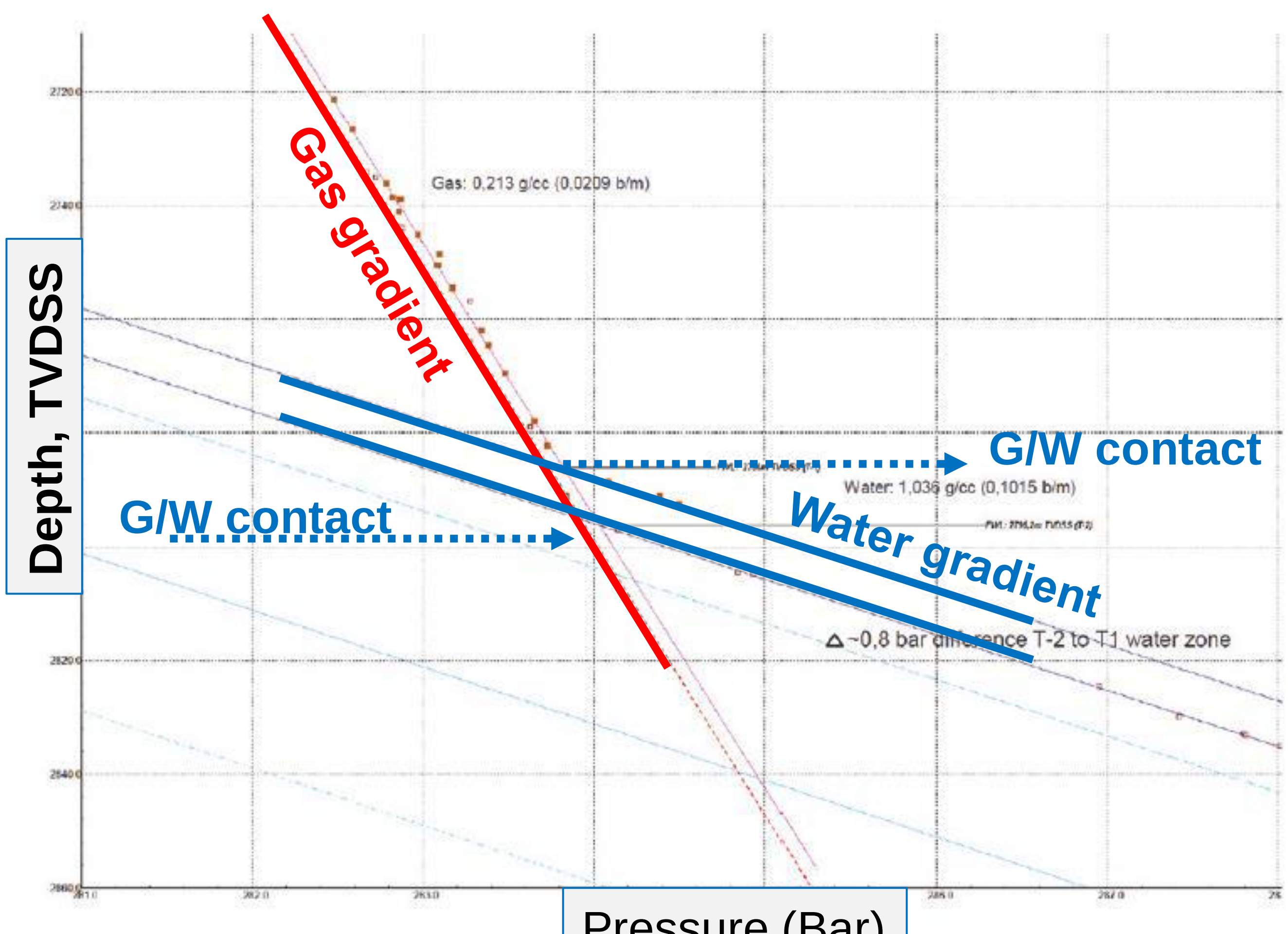


Figure 28. Pressure plot showing differences in the aquifer pressure at the two well locations.

m S

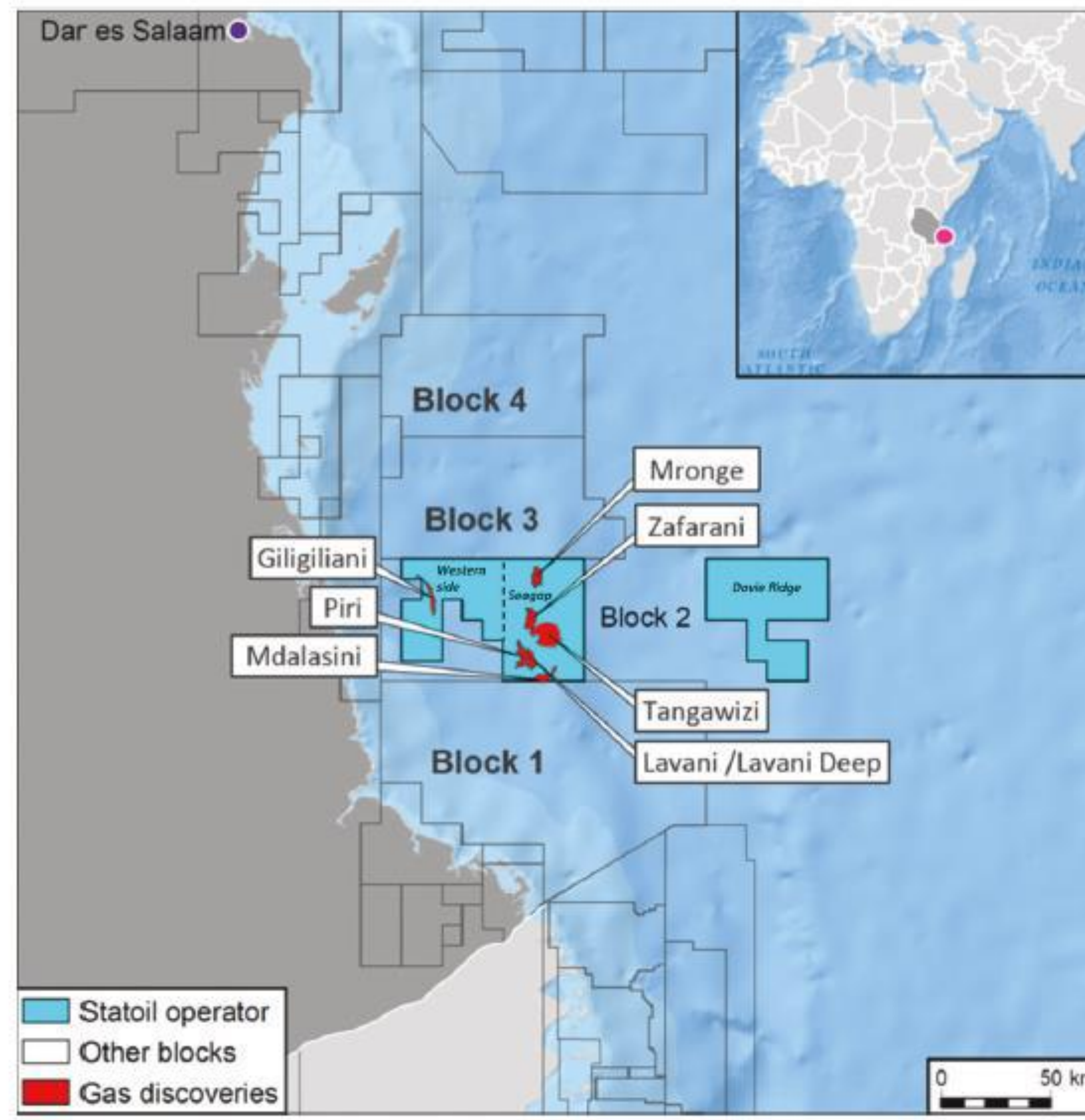
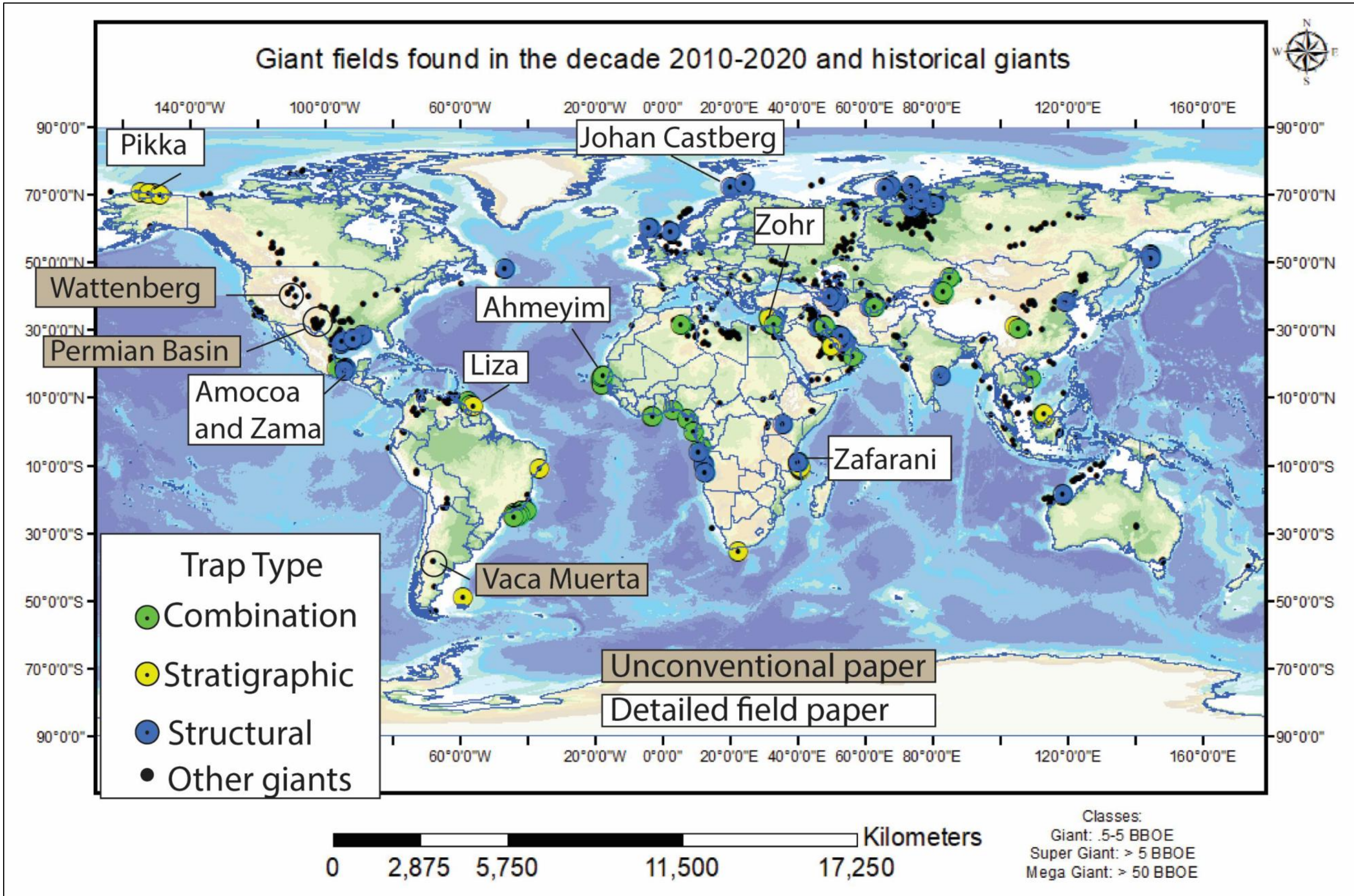


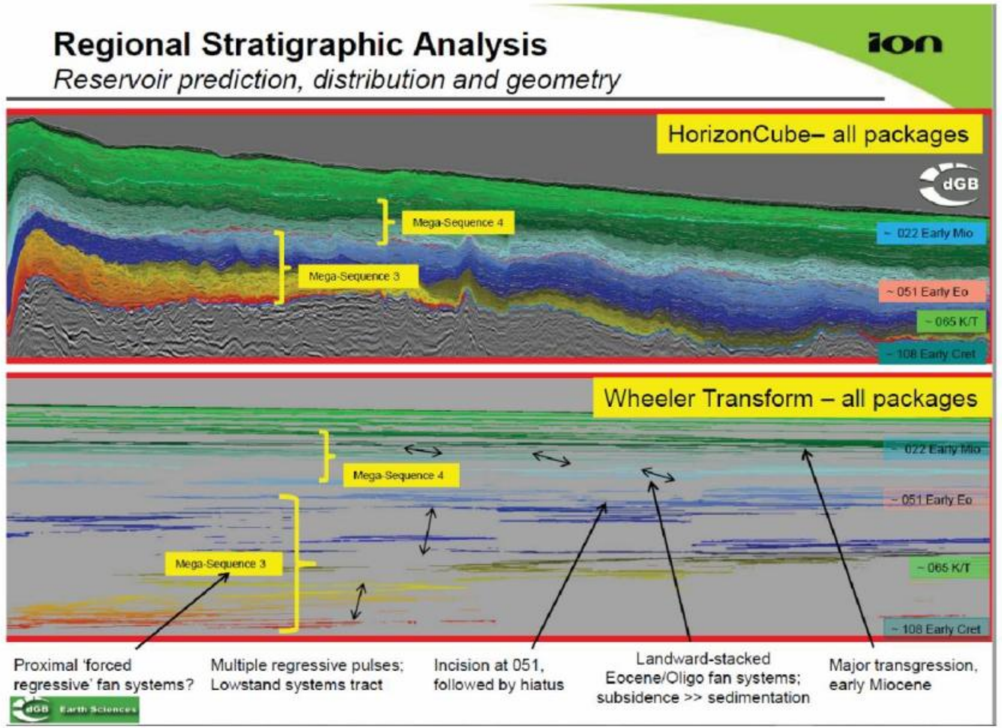
Figure 1. Block 2 location with discoveries after first block relinquishment.

AAPG Giant Fields volume at September, 2021 Image Conference, Denver, Colorado

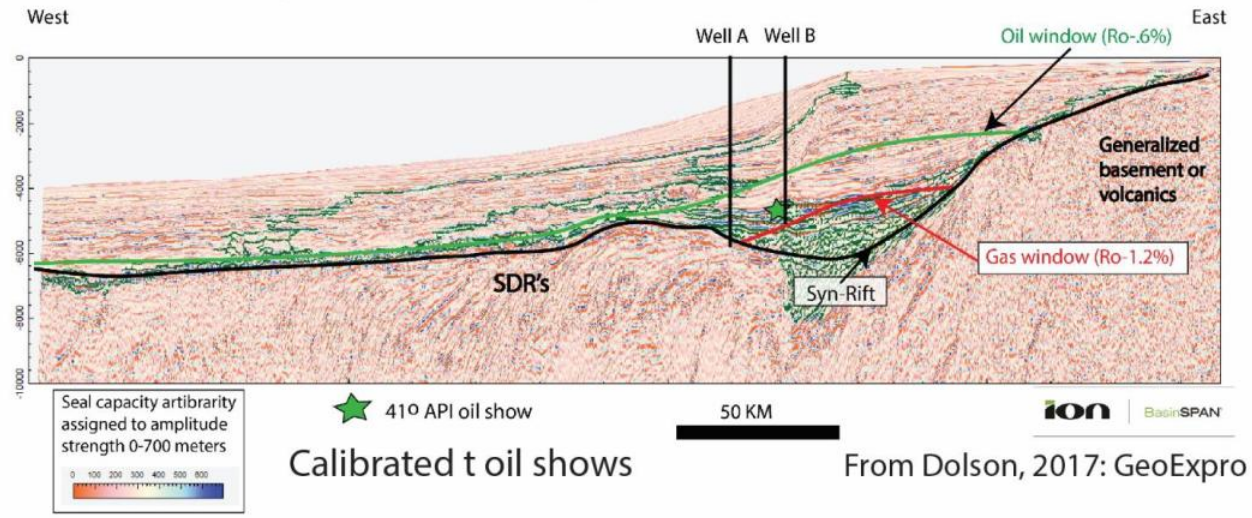


Some other tools that unlock new ideas

A. Wheeler transform from seismic

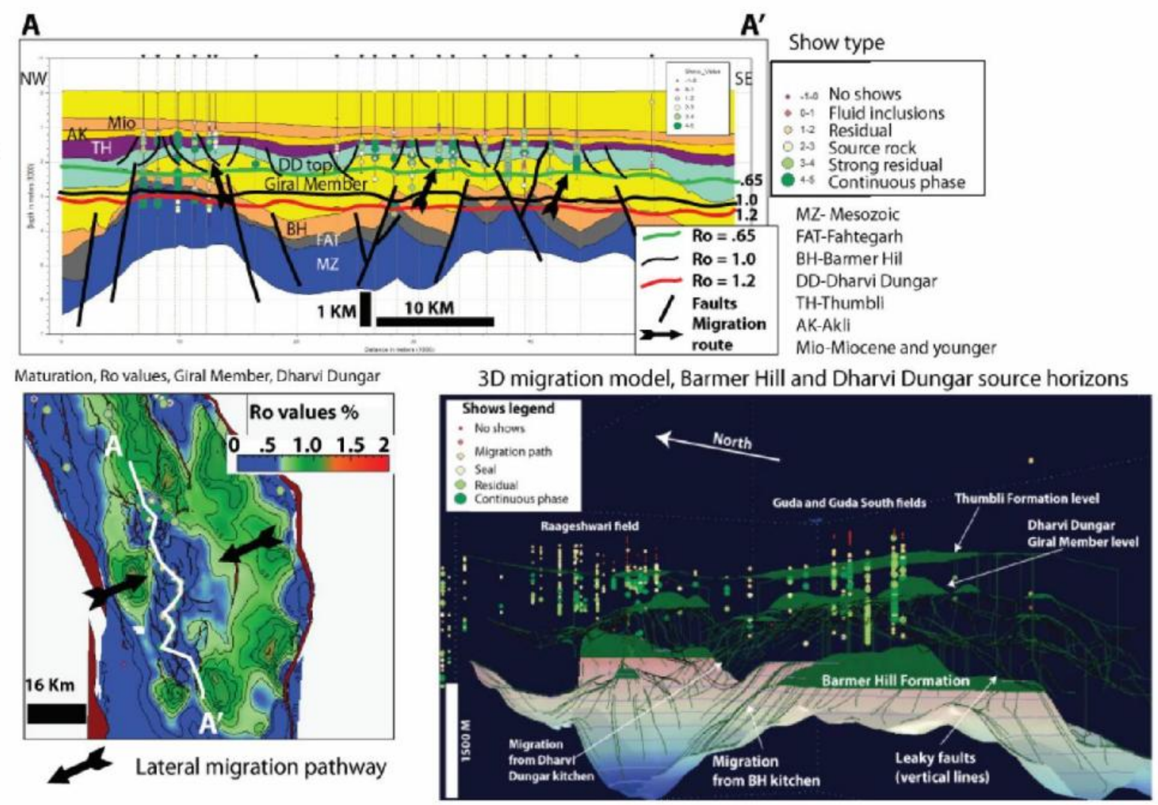


B. Trinity quick look migration from depth seismic



Modeling 3D migration calibrated to oil geochemistry

D.

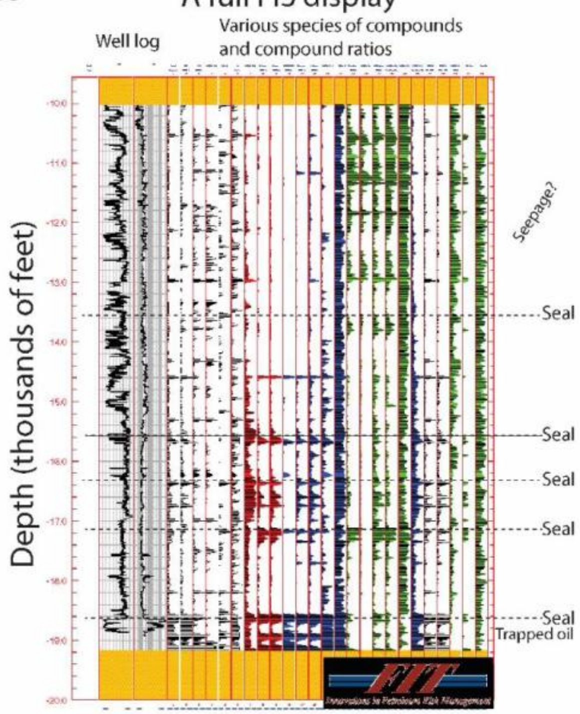


From Dolson, 2016

Fluid Inclusions Stratigraphy: New Looks, Old Wells

C.

A full FIS display

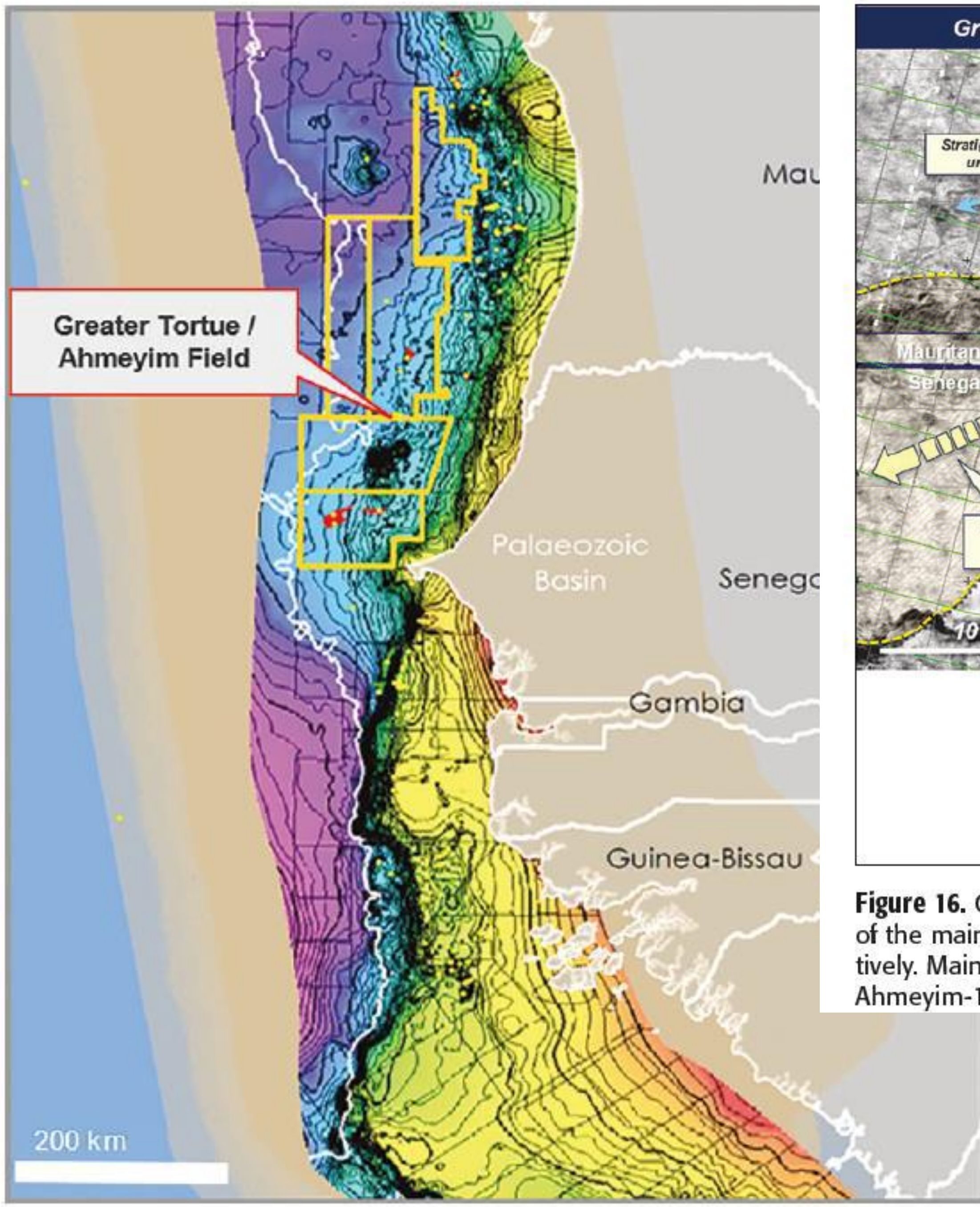


Color legend:
Black : Inorganics
Red : Low molecular weight organic
Blue : Water soluble compounds
Green: Higher molecular weights

Useful information from these plots
* seals shown at vertical breaks
--potential migration pathways under the seals
* potential charged reservoirs
* possible by-passed pay
* proximity to pay
* micro-seepage near surface

From Dolson, 2016

Giant Ahmeyim-Deep Water DHI



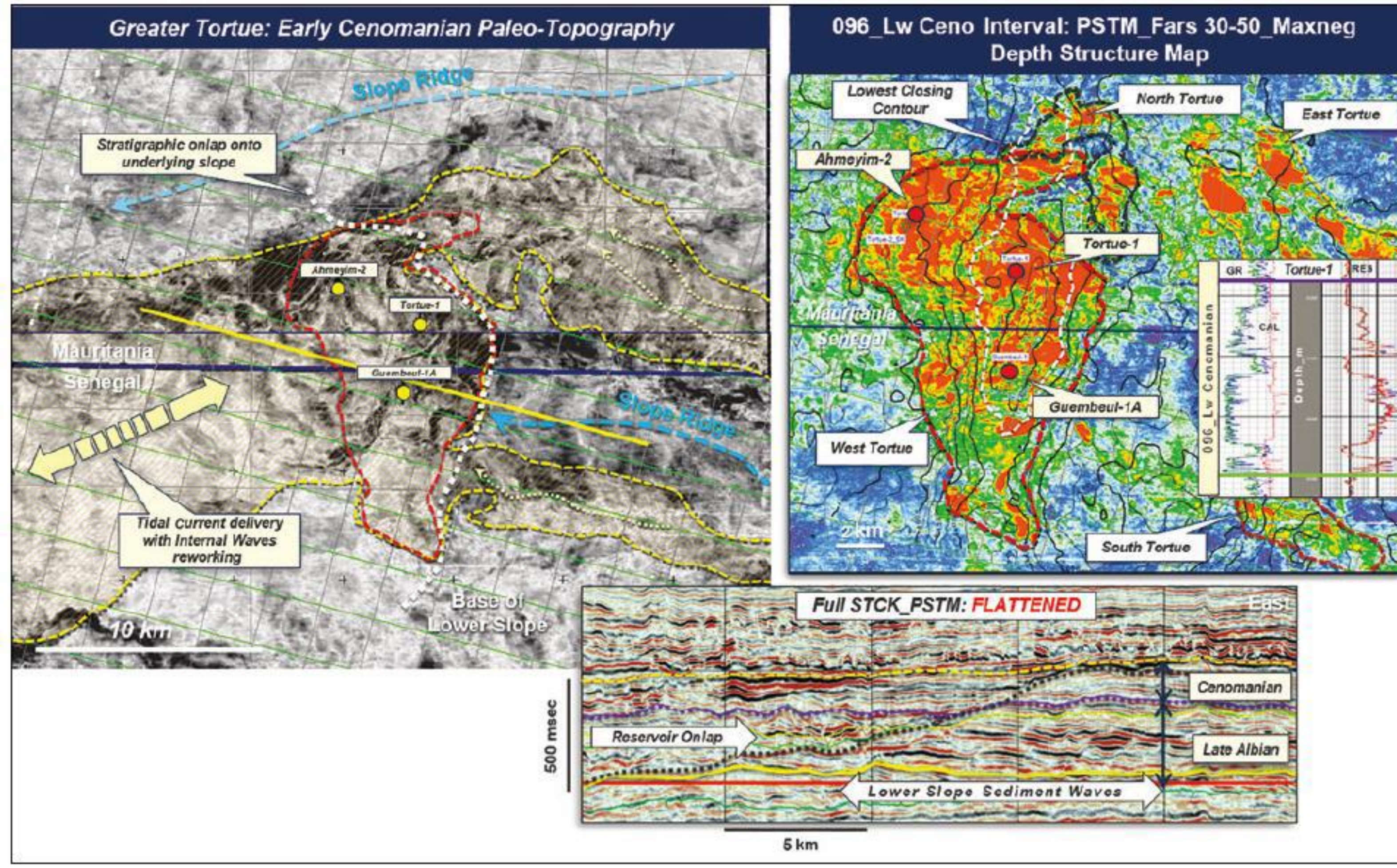
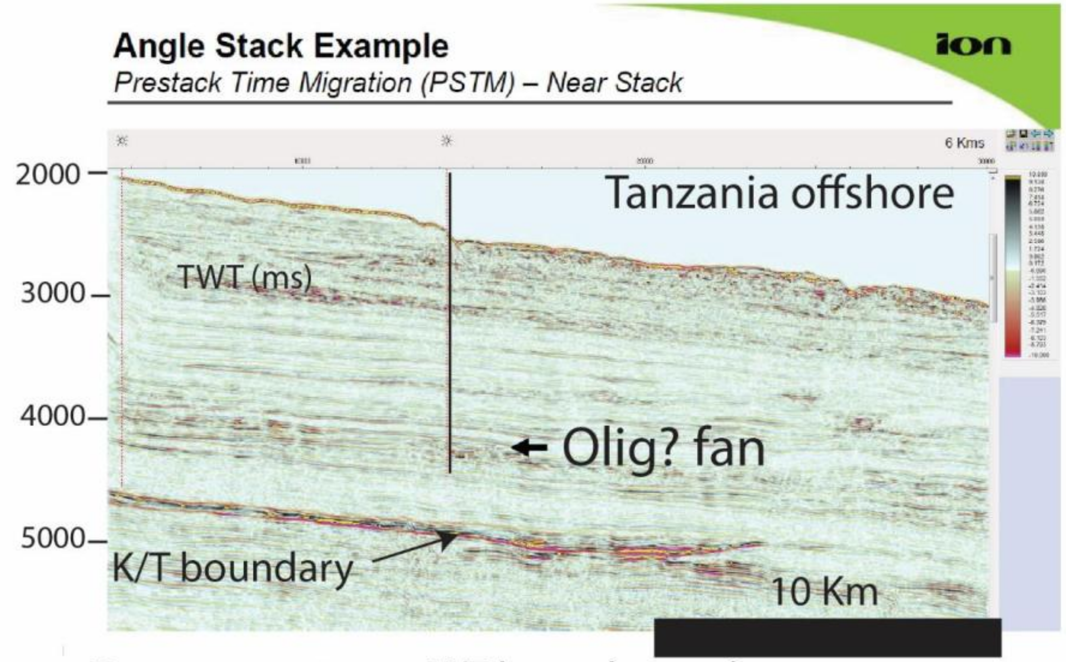


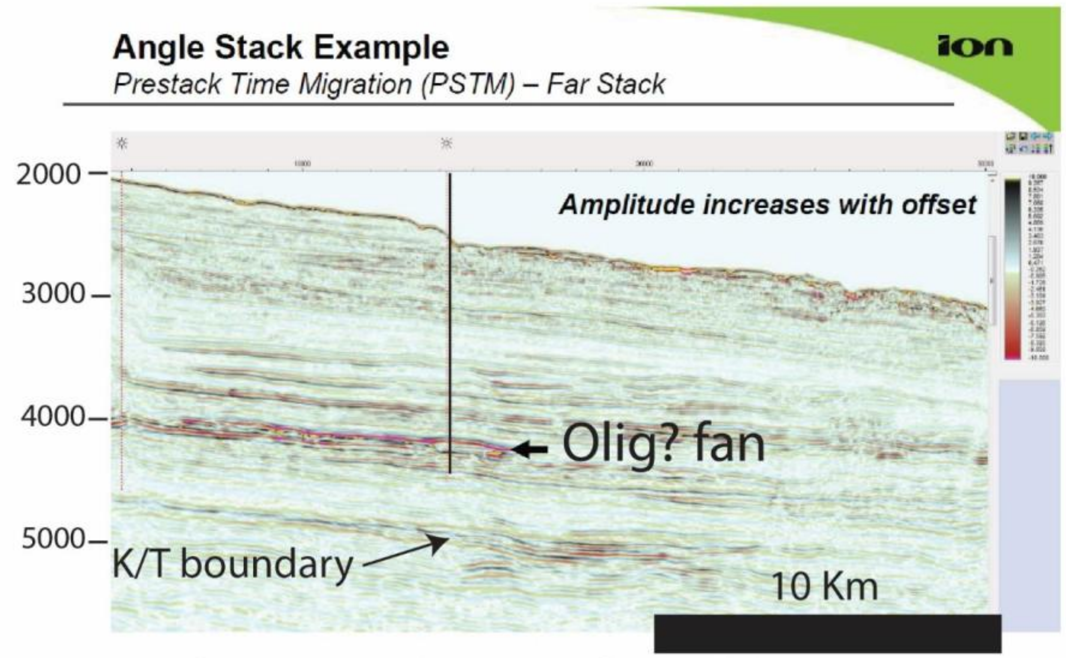
Figure 16. Greater Tortue paleo-depositional setting for the lower slope during the Early Cenomanian. Tortue-1 log section of the main pay interval, showing gamma ray (GR) and resistivity (RES) logs for sand and hydrocarbon response, respectively. Main pay interval amplitude extraction map shows extent of gas-bearing reservoir. (Note: Tortue-1 was renamed Ahmeyim-1.)

Combination trap: 50-100 TCF GIP!
Area ‘written off’ by all major oil companies

Stratigrahpic/Combination Trap Helper: AVO Analysis



Deeper event near K/T boundary only seen on offset stacks: Paleocene? channel trend



Far offset: Bright Oligocene? fan and thick gas pay section. This is a verified discovery where angle stacks provide a basis for DHI (AVO) comparisons

Rock property dependent: do your homework

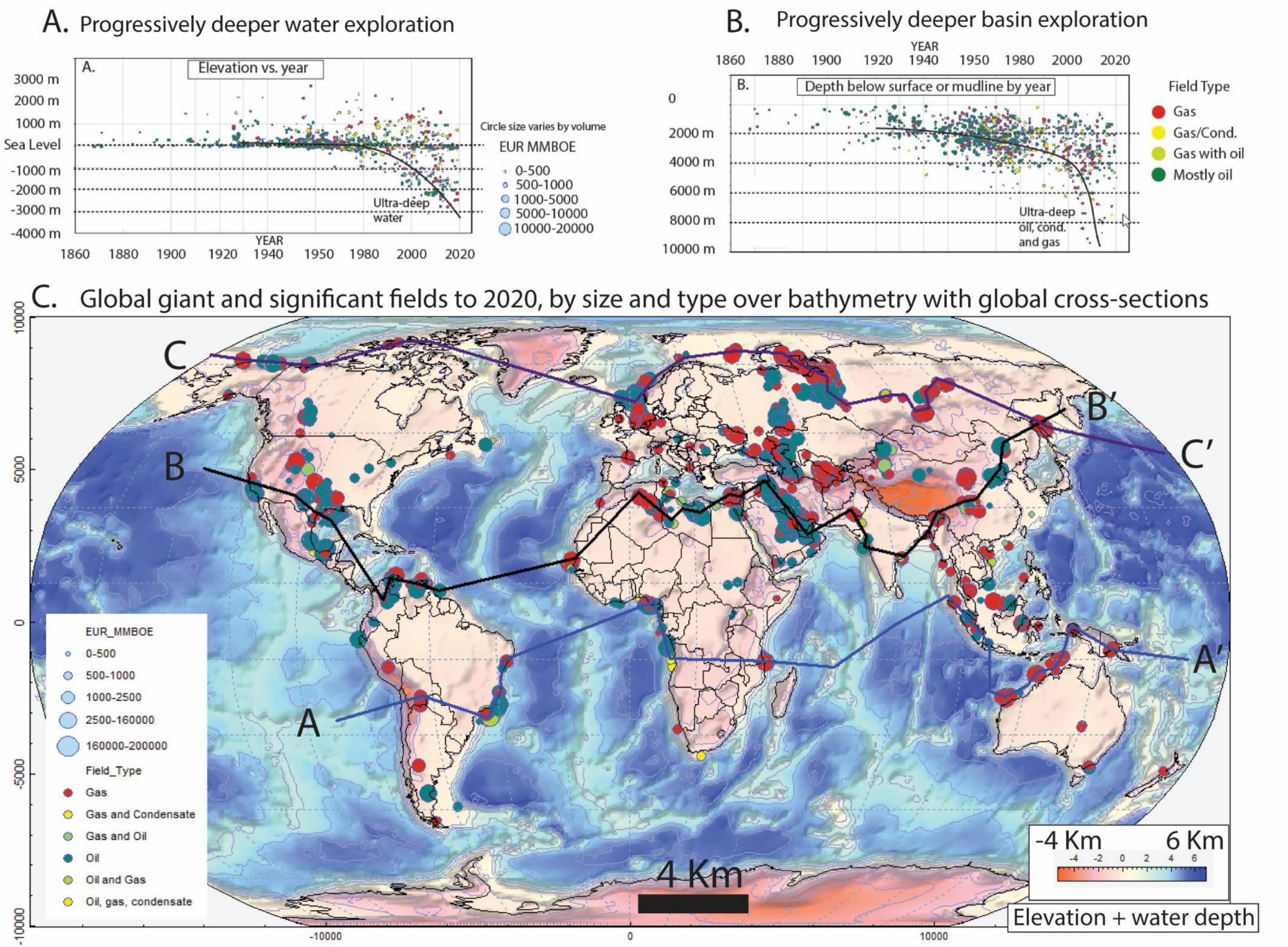
A key factor in giant fan discoveries 2000-2017

Key pitfalls:

AVO analysis shows no conformance to structure
(probably lithology)

Amplitude maps don't look like geology
(amplitudes in space)

Best analysis uses multiple visualization techniques
- Semblance, Seismic wavlet facies and other methods--
  - the image has to look like geology!


A. Progressively deeper water exploration
A.
Elevation vs. year
3000 m
2000 m
1000 m
Sea Level
-1000 m
-2000 m
-3000 m
-4000 m
Ultra-deep water
YEAR
1860 1880 1900 1920 1940 1950 1980 2000 2020
Circle size varies by volume
EUR MMBOE
0-500
500-1000
1000-5000
5000-10000
10000-20000
B. Progressively deeper basin exploration
YEAR
1860 1880 1900 1920 1940 1950 1980 2000 2020
B.
Depth below surface or mudline by year
0
2000 m
4000 m
6000 m
8000 m
10000 m
Ultra-deep oil, cond. and gas
Field Type
Gas
Gas/Cond.
Gas with oil
Mostly oil
C. Global giant and significant fields to 2020, by size and type over bathymetry with global cross-sections
C
C′
B
B′
A
A′
EUR_MMBOE
0-500
500-1000
1000-2500
2500-160000
160000-200000
Field_Type
Gas
Gas and Condensate
Gas and Oil
Oil
Oil and Gas
Oil, gas, condensate
4 Km
-4 Km
6 Km
-4 -2 0 2 4 6
Elevation + water depth
10000
5000
0
-5000
-10000
-10000
0
10000

Multiple basins and play types: Until the last 20 years, giants were dominated by structural traps (80-90%). Unconventional and strat-combination traps are becoming the most dominant trap types with advances in 3D seismic and unlocking tight rocks with horizontal drilling.