Structural Setting of Turbidite Systems: A Global Comparison*

Berend van Hoorn[1]

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Abstract

Over the last 25 years exploration and production in deepwater (in water depth in excess of 500 m) has increased greatly to the point that a considerable amount of today's industry budget is spent on these activities. Whereas initially little was known about the geological setting of deepwater systems (and few people believed in the presence of sandstone reservoirs beyond the continental shelf edge), we now know that downdip of several Neogene deltas, major turbidite systems occur with appreciable reserves of oil and gas. Oil accumulations in turbidite sandstones are not new, in fact production from these reservoirs has been going on in the Mio-Pliocene Los Angeles and San Joaquin pull-apart basins in California before Kuenen coined the term in 1957. Similarly, sizeable accumulations have been found in Upper Jurassic, Lower Cretaceous and Lower Tertiary turbidite sequences in the North Sea in a rift-sag setting, described by Peter Ziegler in his Geological Atlas of Western and Central Europe.

In the mid-eighties exploration moved into deeper water and driven by successes in the Gulf of Mexico, further efforts focused on the Lower Congo Basin, Campos Basin and offshore Nigeria. A common characteristic of these four basins is that the turbidite depocentres overlie a mobile substrate of salt or overpressured shale which provide a high density of traps with a similar and predictable structural/stratigraphic evolution, stacked reservoir/seal pairs, and an easy access to mature source rocks. A regional comparison of these basins suggests that in a general sense four structural play types can be defined: (1) Immediately downdip from the major deltaic expanders, an area of Inner Folds with large trap closures postdating the emplacement of

channelized turbidite reservoirs (Angola. Nigeria); (2) An area of minibasins where structuration and sedimentation are more or less coeval leading to the emplacement of stacked confined turbidite sheetsands (Gulf of Mexico); (3) In areas of salt withdrawal, inversion of minibasins with turbidite sheet sands leads to the formation of turtles (Angola, Brazil. Gulf of Mexico); (4) An oceanward area of very large outer folds which are structurally coupled to deltaic extension updip and where amalgamated unconfined turbidite channels and sheets occur predating trap formation (Perdido, Gulf of Mexico, possibly deepwater Colombia, Malaysia).

Exploration efforts in turbidite basins without a mobile substrate have so far been more limited and concentrated on the Atlantic margins of the United Kingdom and Norway. Typically the density of structural closures is low but individual structures can be very large in areal extent, quite often with a stratigraphic component. Recently, major discoveries in Equatorial Africa have spurred the industry to take a closer look at the Cretaceous turbidite systems on both sides of the African-South American conjugate margin in what is a very lightly explored play setting. Similarly, major gas discoveries in Tertiary turbidites off eastern Africa and India also have indicated that there are still some major frontier deepwater basins worth looking at where structural plays are less obvious.

Selected Reference

Bennett, K.C., and D. Rusk, 2002, Regional 2D seismic interpretation and exploration potential of offshore deepwater Sierra Leone and Liberia, West Africa: The Leading Edge, v. 21, p. 1118-1124.

STRUCTURAL SETTING OF TURBIDITE SYSTEMS, A GLOBAL COMPARISON

Berend van Hoorn

Dedicated to Peter Ziegler

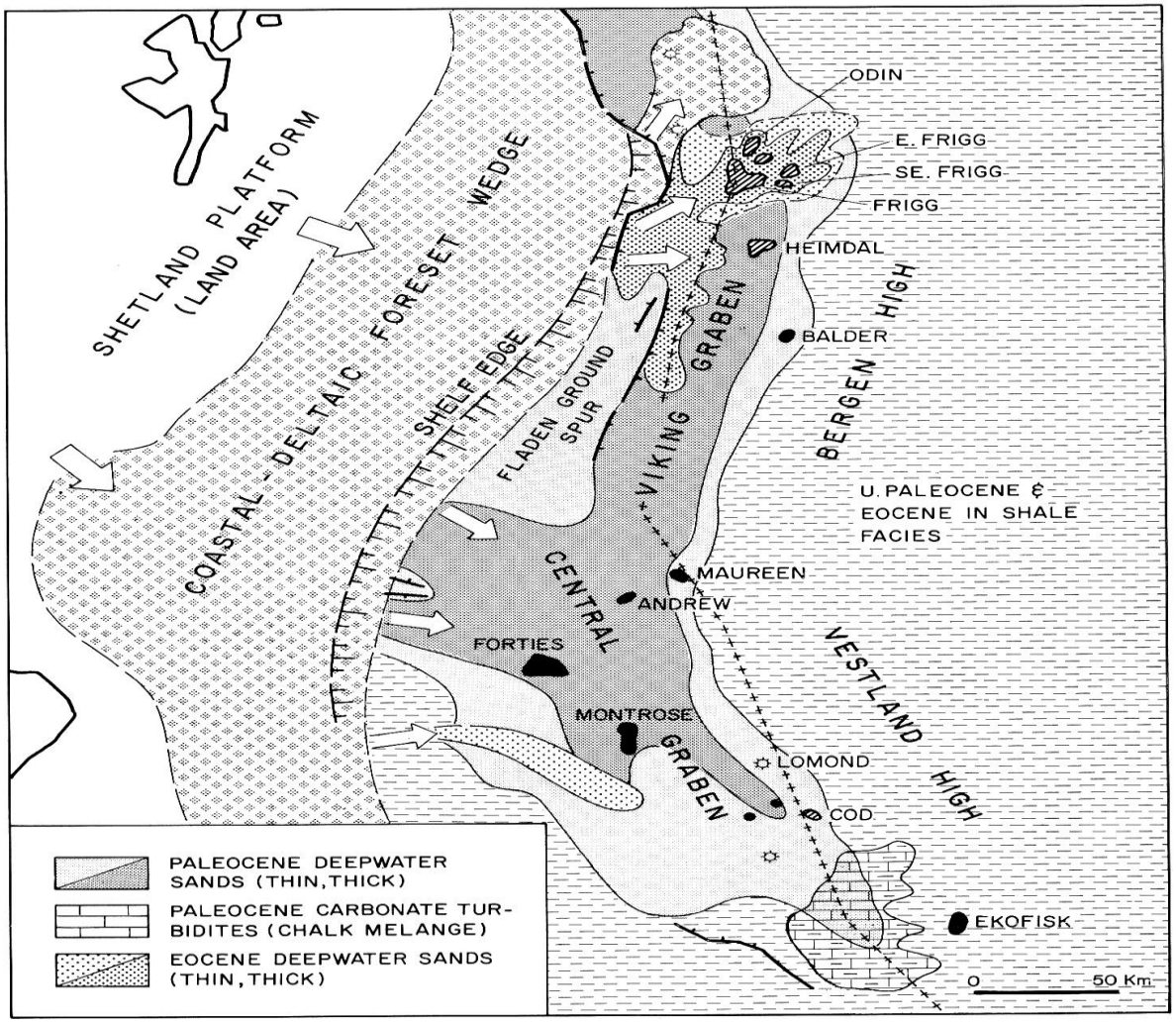


Fig. 68. Schematic facies map late Paleocene and early Eocene clastics, central and northern North Sea (after Ziegler and Louwerens, 1978).

Pin Line

OBJECTIVES

- **Provide a regional tectonic setting of turbidite systems in present-day deepwater**

- **Illustrate analogies and differences between turbidite play types based on structure**

- **Draw some high level observations on the exploration potential of turbidite plays**

Turbidite Basins overlying:

Mobile Substrate (Shale or Salt cored)

Stable Substrate (Basement faulting only)

Passive and Active Margin Deepwater Systems

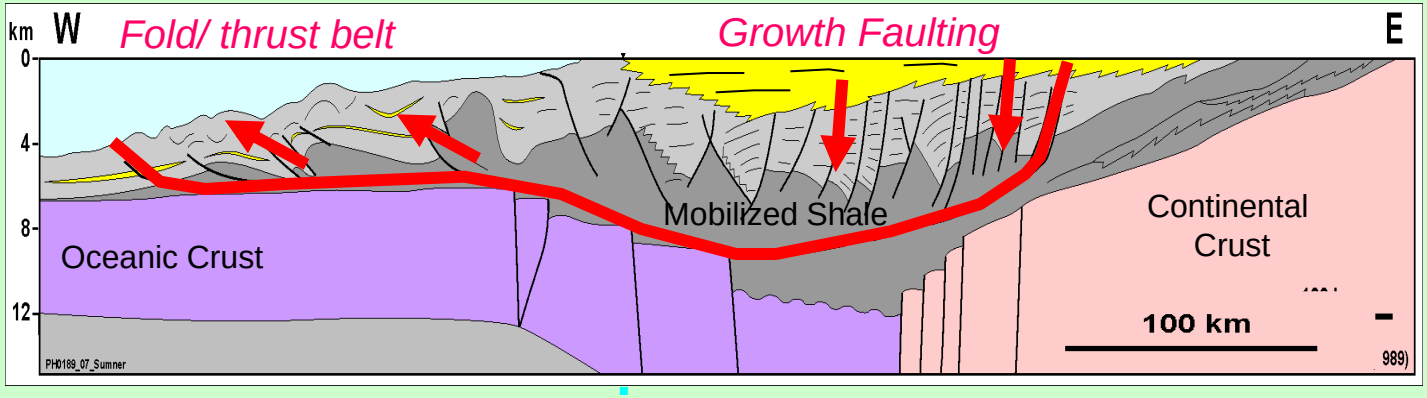
Passive Margin

Shelf Edge

Nigeria

"Linked System"

Updip extension and loading balanced by downdip contraction



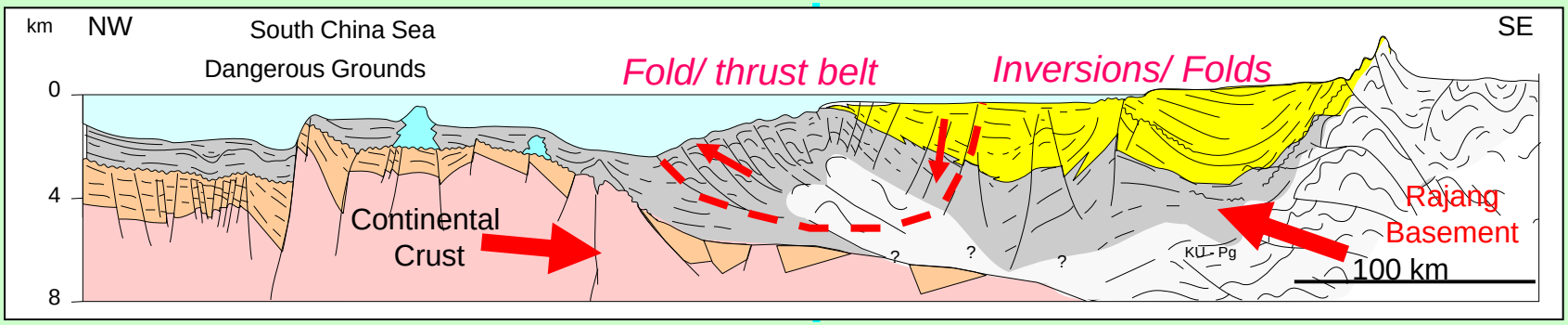
Modified after Doust and Omstala (1989), Haan, (1994)

10 km

100 km

Active Margin

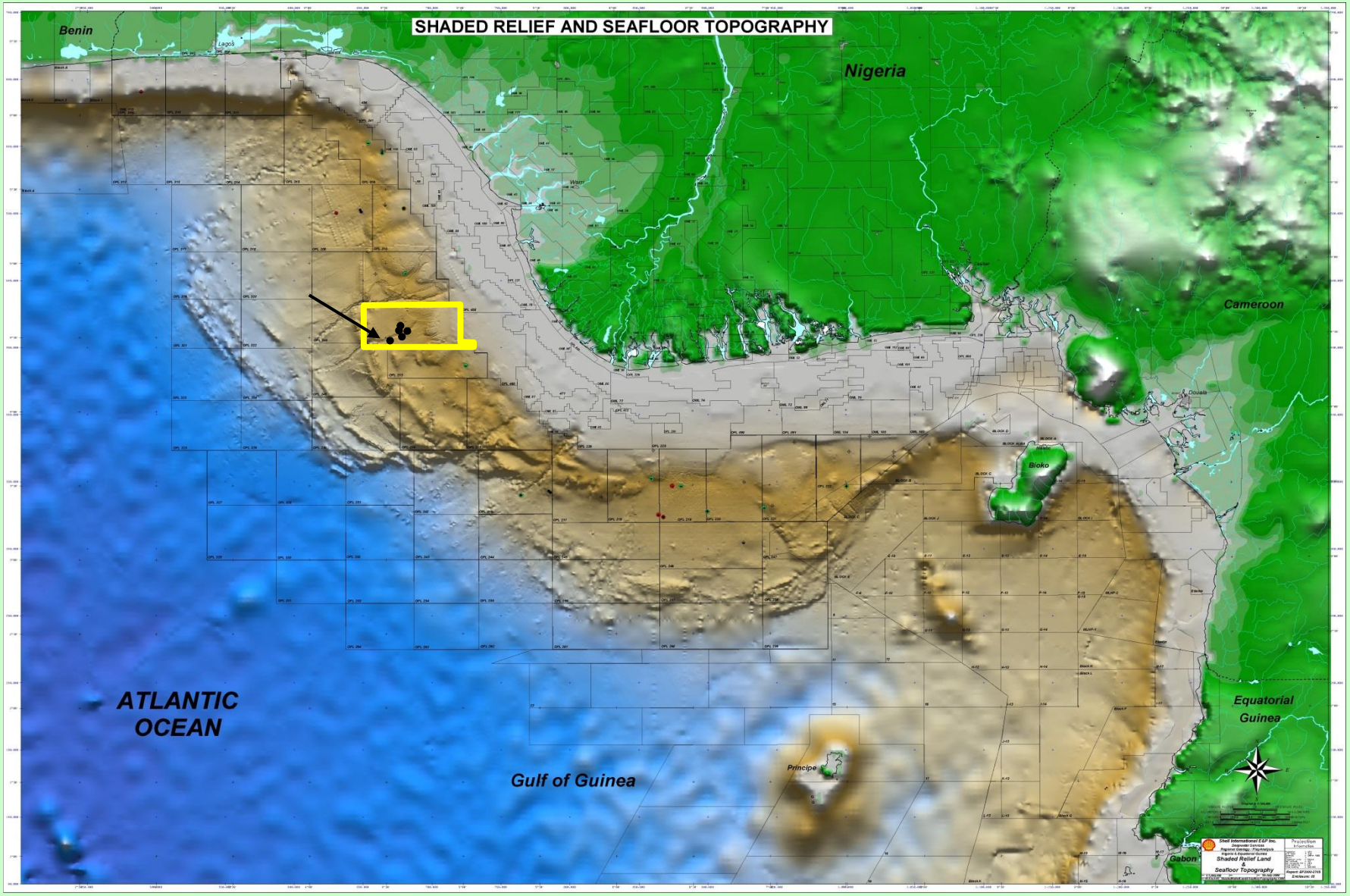
NW Borneo



Mod. after Letouzey and Sage(1988)

Unbalanced system with contraction throughout slope and shelf. May have "thin-skinned linked system" superimposed.

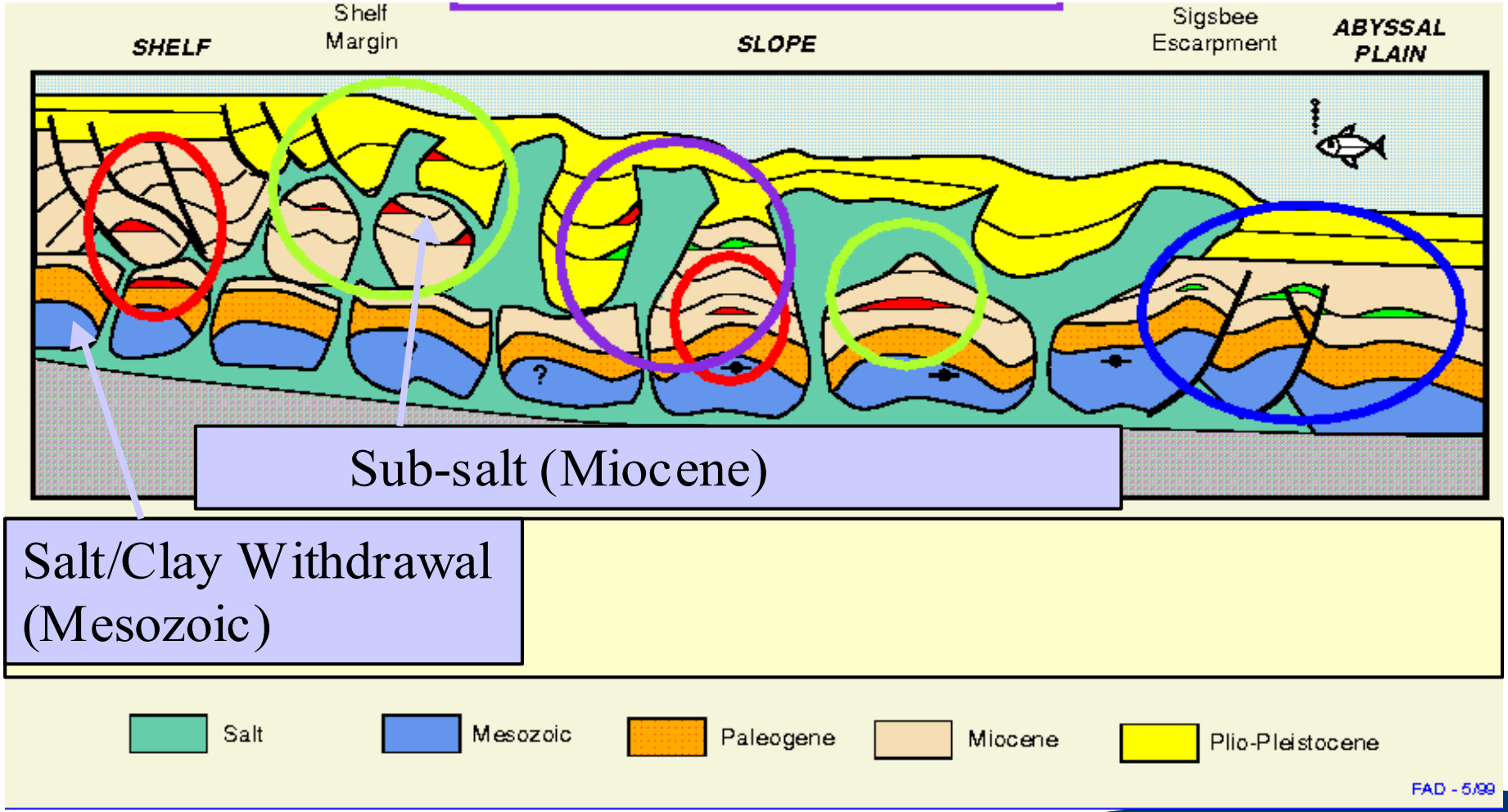
SEAFLOOR IMAGE DW NIGERIA

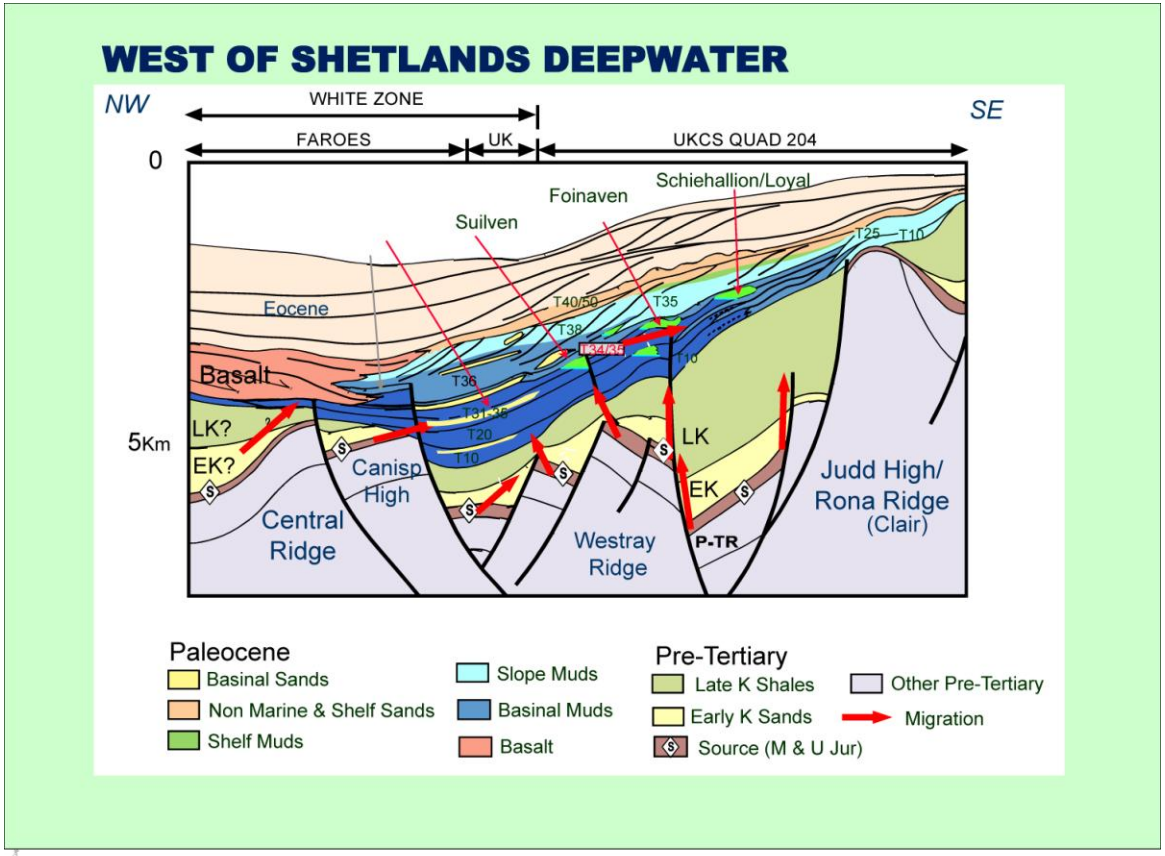


USA - GULF OF MEXICO: ILLUSTRATIVE CROSS-SECTION

Sub-Salt	Toe of slope/ Foldbelt	Abys-sal Plain

Minibasin/Diapir flank (Pliocene)





Presenter's notes:

Highlight:

1) Deep structure with potential fluid focii
2) Source Rocks
3) Cretaceous thicks & thins
4) E-M Cretaceous key carriers Late Cretaceous dom mdst
5) Paleocene thick depocentre
6) Carriers, T20-35 Fields
7) T36 Regional Seal
8) Basalt
9) Eocene depocentre
10) Depocentre migration
11) Approx locn Faroes prospects

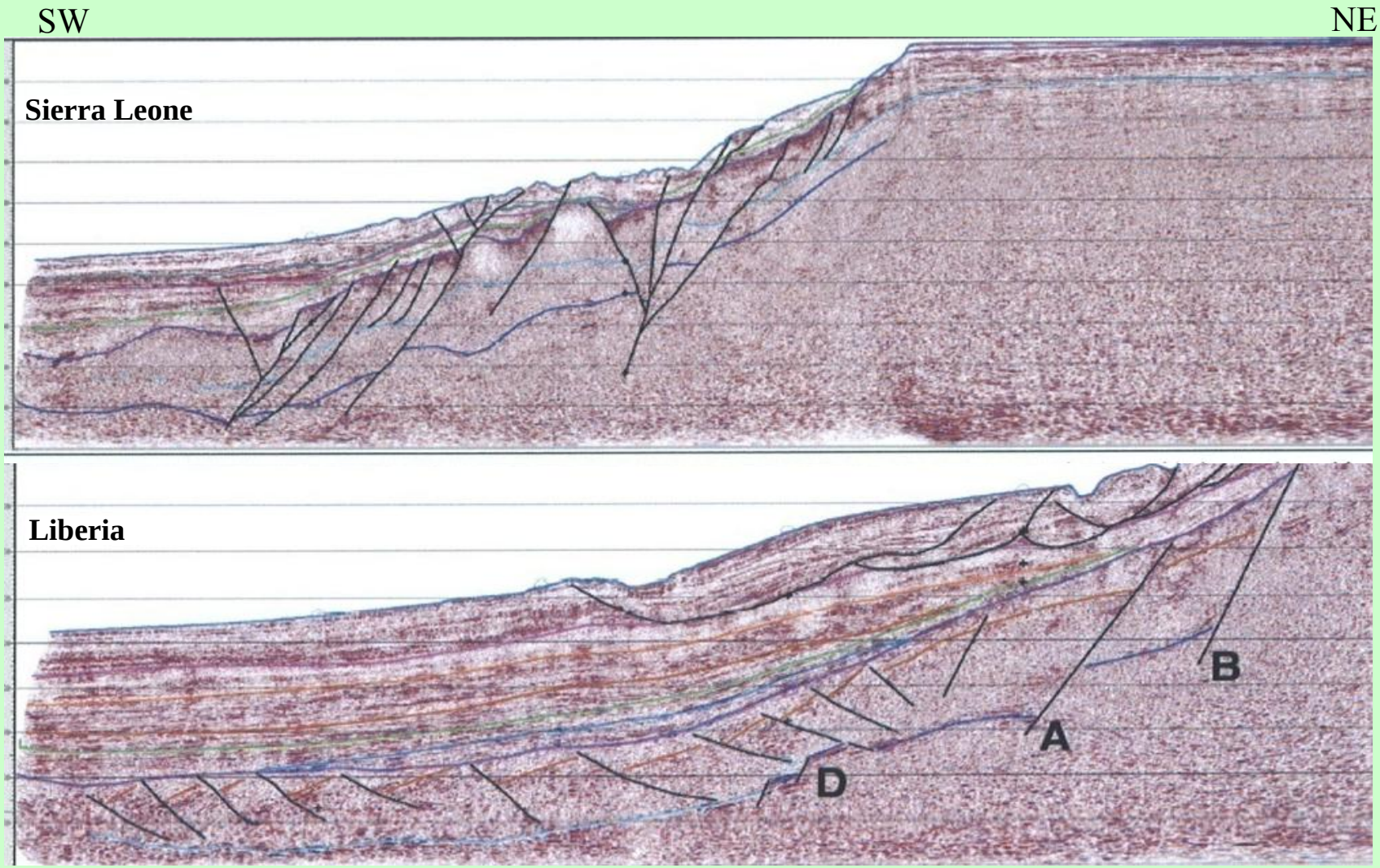
(Presenter's notes continued on next slide)

(Presenter's notes continued from previous slide)

Geochemistry:
- Indicates 2 charge events for Schiehallion, Foinaven, and Loyal fields
First in Eocence, second present-day RSA analysis
- Suggests lateral connectivity and fill is controlled by W-E faulting Basin modelling
- Predicts 2 charge events above for the fields

Predicts single oil charge event (present day) for outboard prospects.
Pre-drill gross depositional model for Paleocene outboard of the existing fields.
Passive basin fill - sands deposited in an overall mud-dominated basin.
Source from the SE via Foinaven and Schiehallion fields.
Multiple reservoir-seal pairs attributed to 'flooding surface/sandy fan' deposition cycles.
Specific prospects were isolated at the base of the slope due to up-dip sediment bypass, mudstone drape and cross faulting.

EQUATORIAL AFRICA REGIONAL DIP LINES



Extensive rift-faulting beneath the Mid-Cretaceous unconformity (purple horizon), followed by onlapping passive margin deposits in the post-rift section

(After Bennett & Rusk, 2002)

TURBIDITE PLAYS OVERLYING A MOBILE SUBSTRATE

(Cored by salt or overpressurized shale)

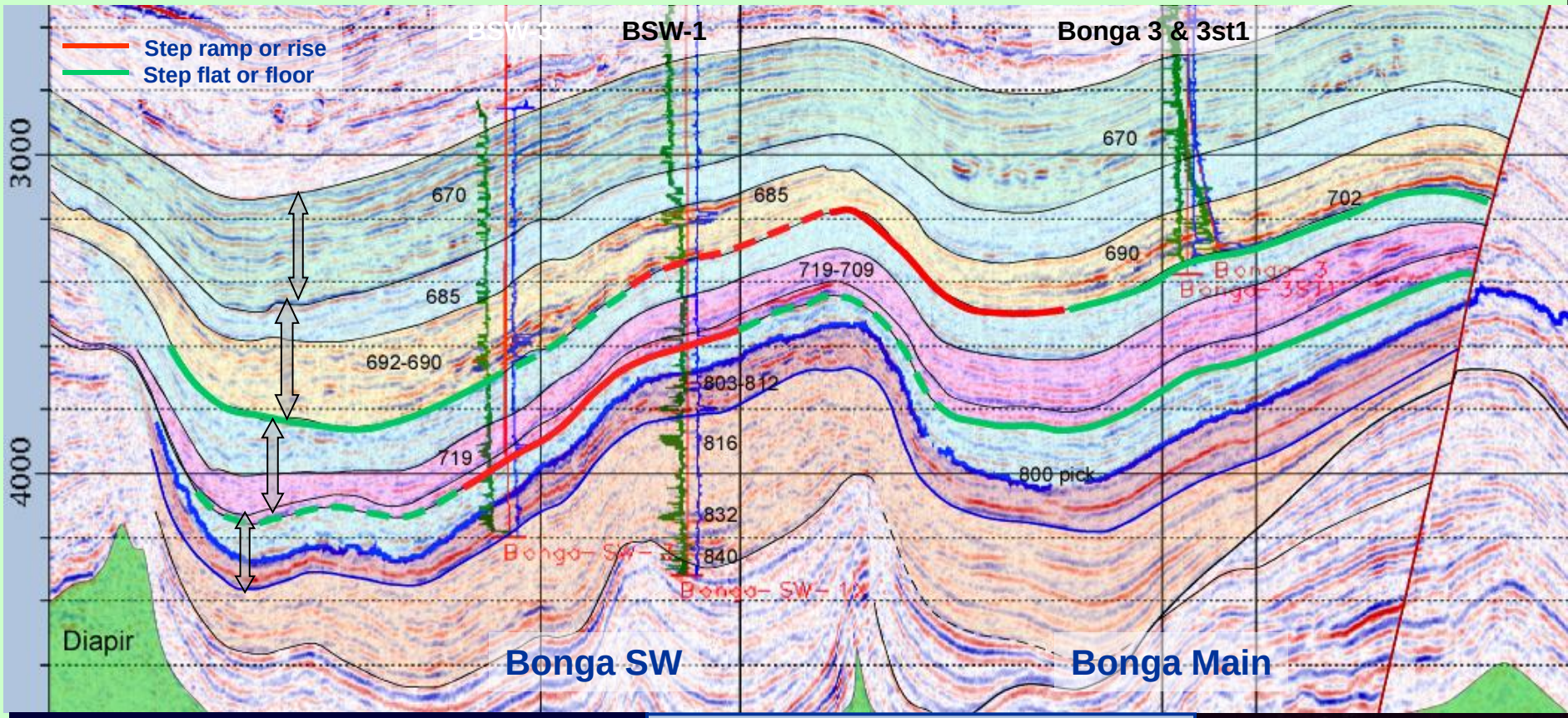
INNER FOLDS

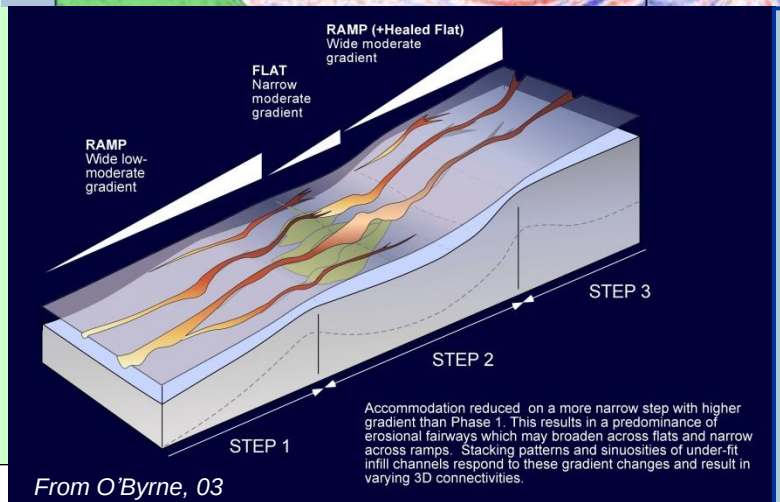
MINIBASINS TURTLES (In salt basins)

OUTER FOLDS

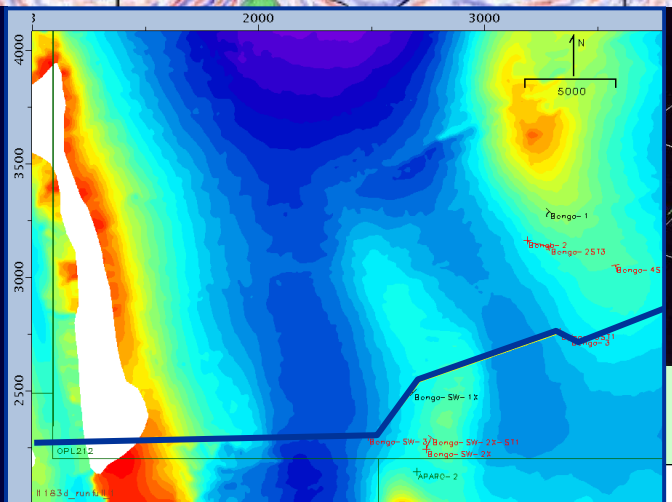
INNER FOLDS

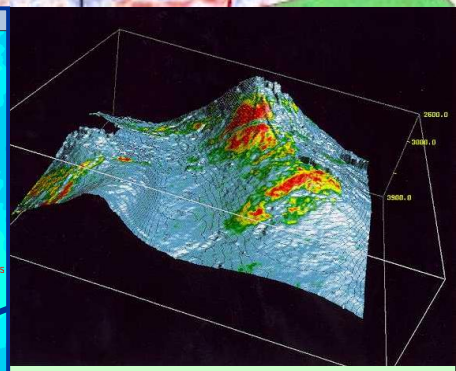
INNER FOLDS DEEPWATER NIGERIA (Bonga)





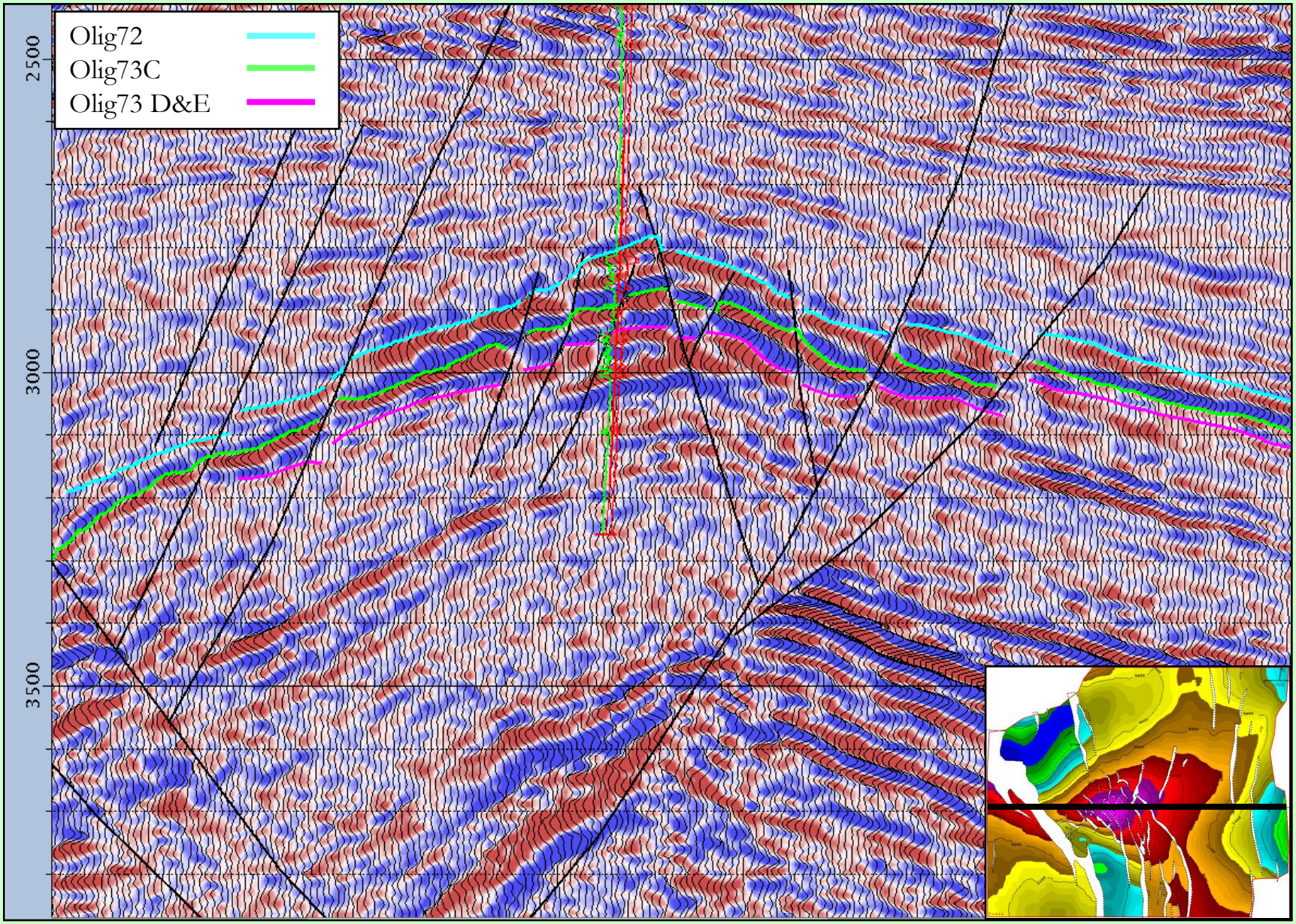
From O'Byrne, 03





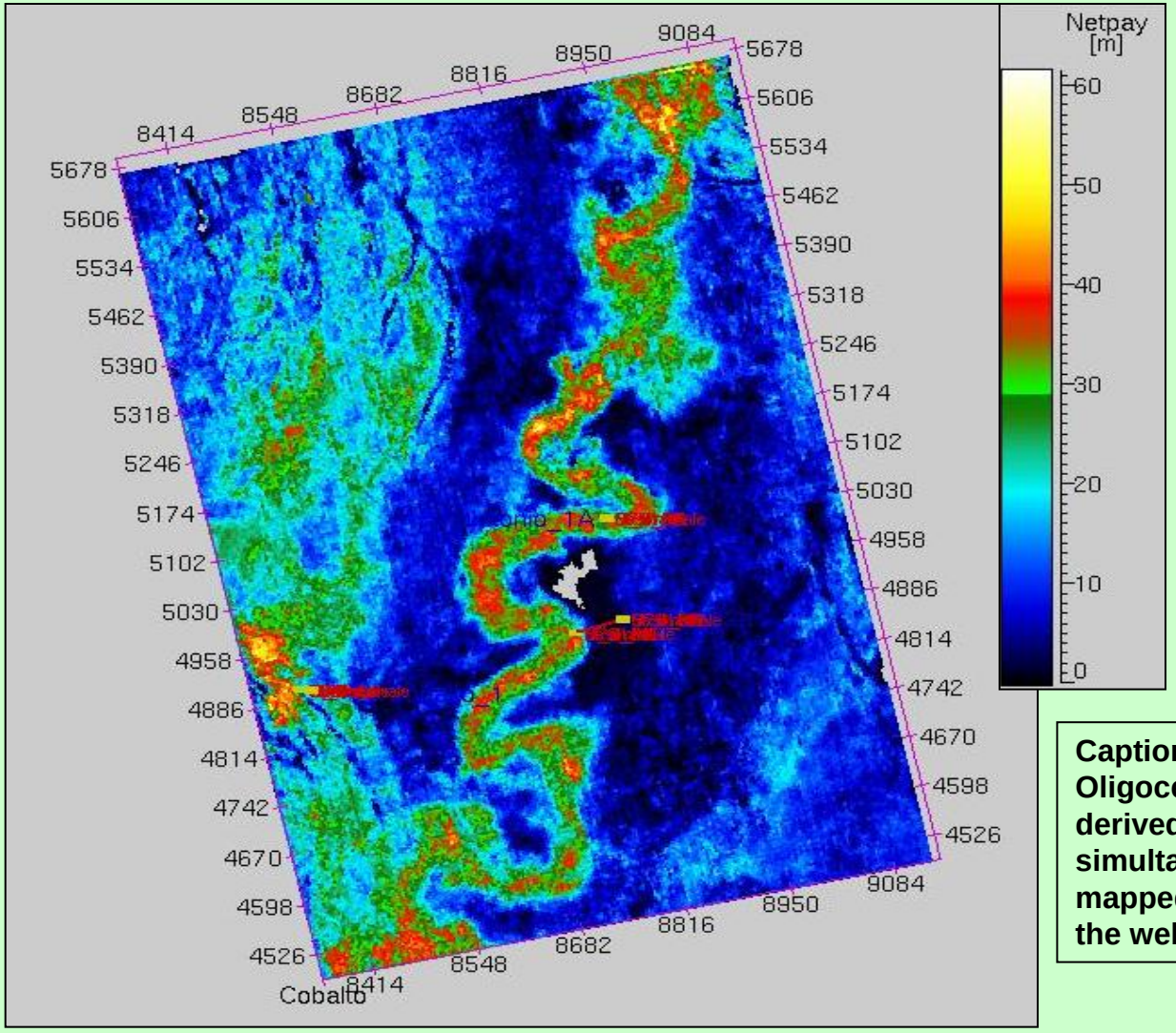
INNER FOLDS CONGO BASIN

W E



Lithology Cube Data

INNER FOLDS CONGO BASIN



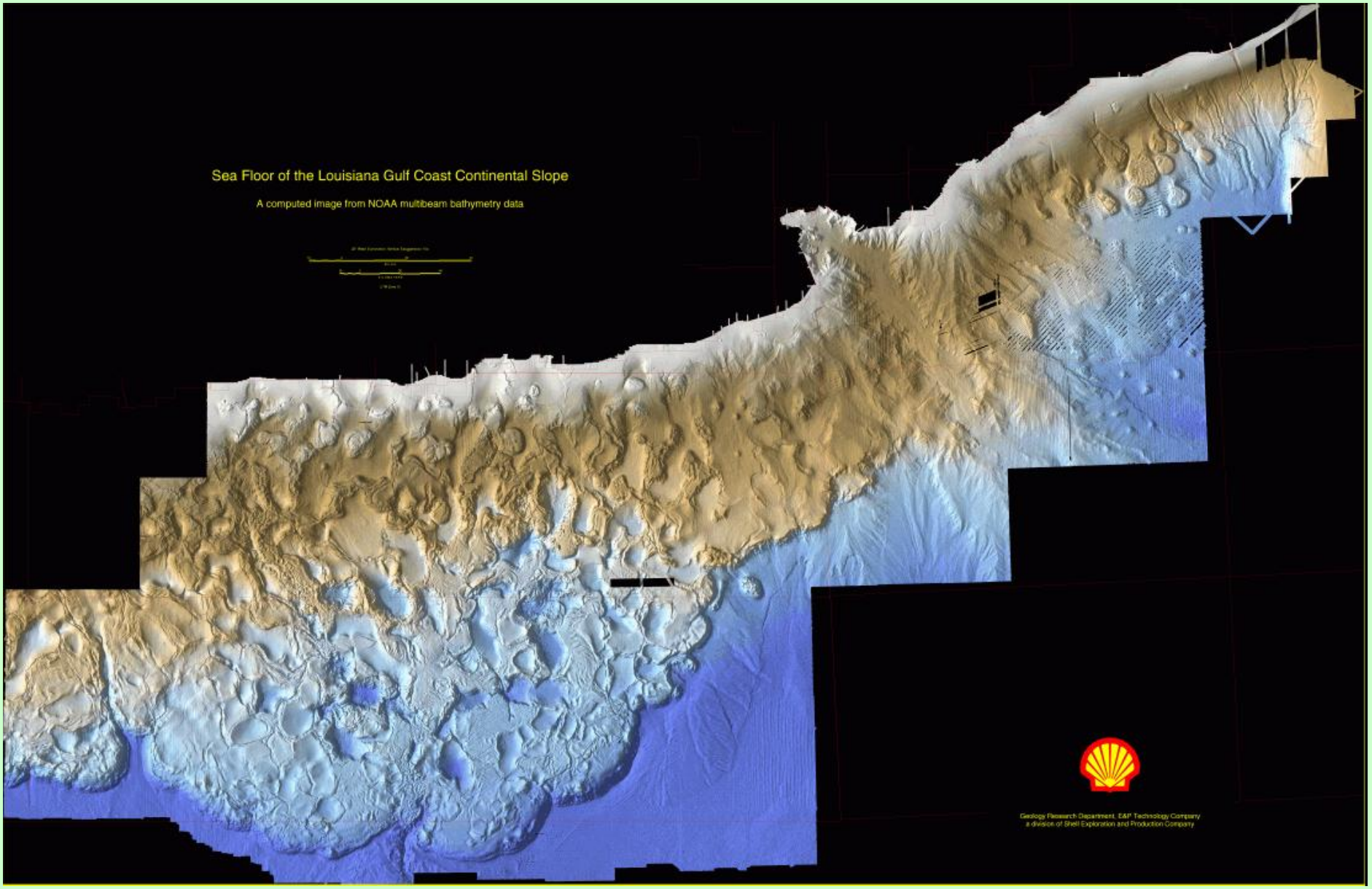
Caption: Net sand map for an Oligocene meandering channel, derived from calibrating a simultaneous AVO inversion to mapped events and net-to-gross in the wells

INNER FOLDS

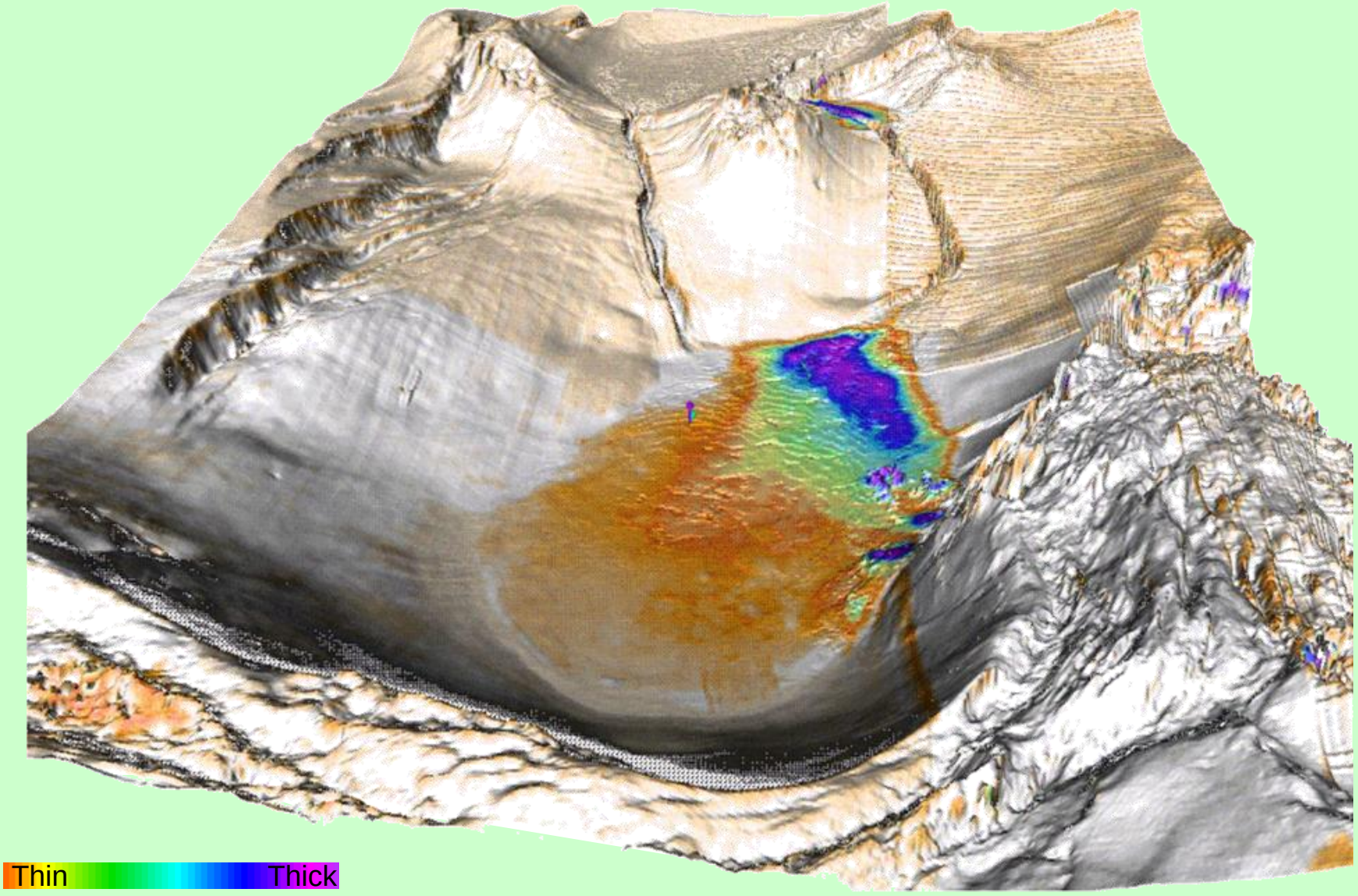
- High success rate in areas of mature source rocks
- No charge limitations
- Channelized turbidite reservoirs, limited lateral extent
- Because of crestal faulting, good regional seals are required to retain hydrocarbons
- Large symmetrical closures, medium lead density
- Structuration related to rapid depostion of young overburden over thick mobile layer

MINI-BASINS

GULF OF MEXICO SEAFLOOR IMAGE

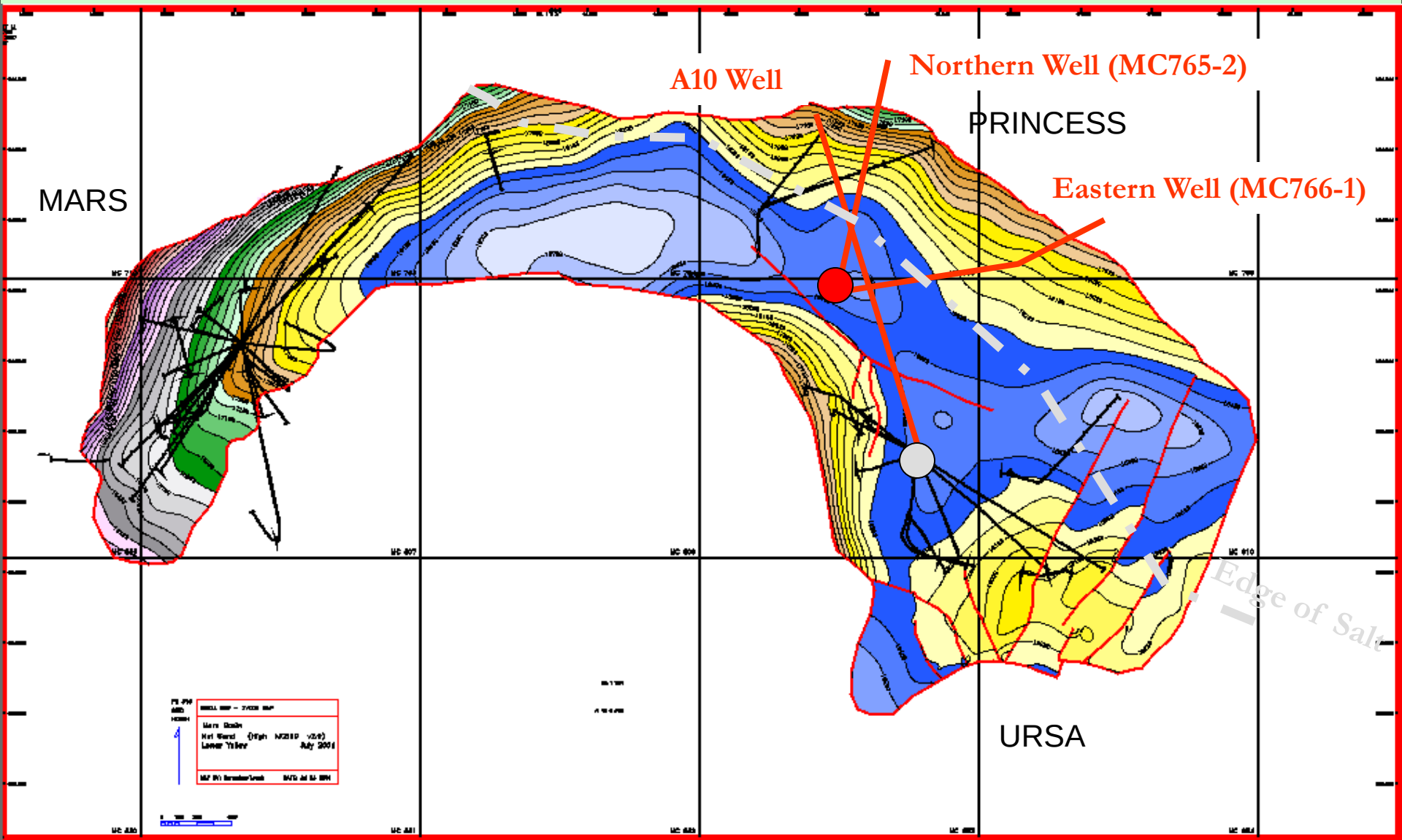


Fan System Evolution in Minibasins Gulf of Mexico

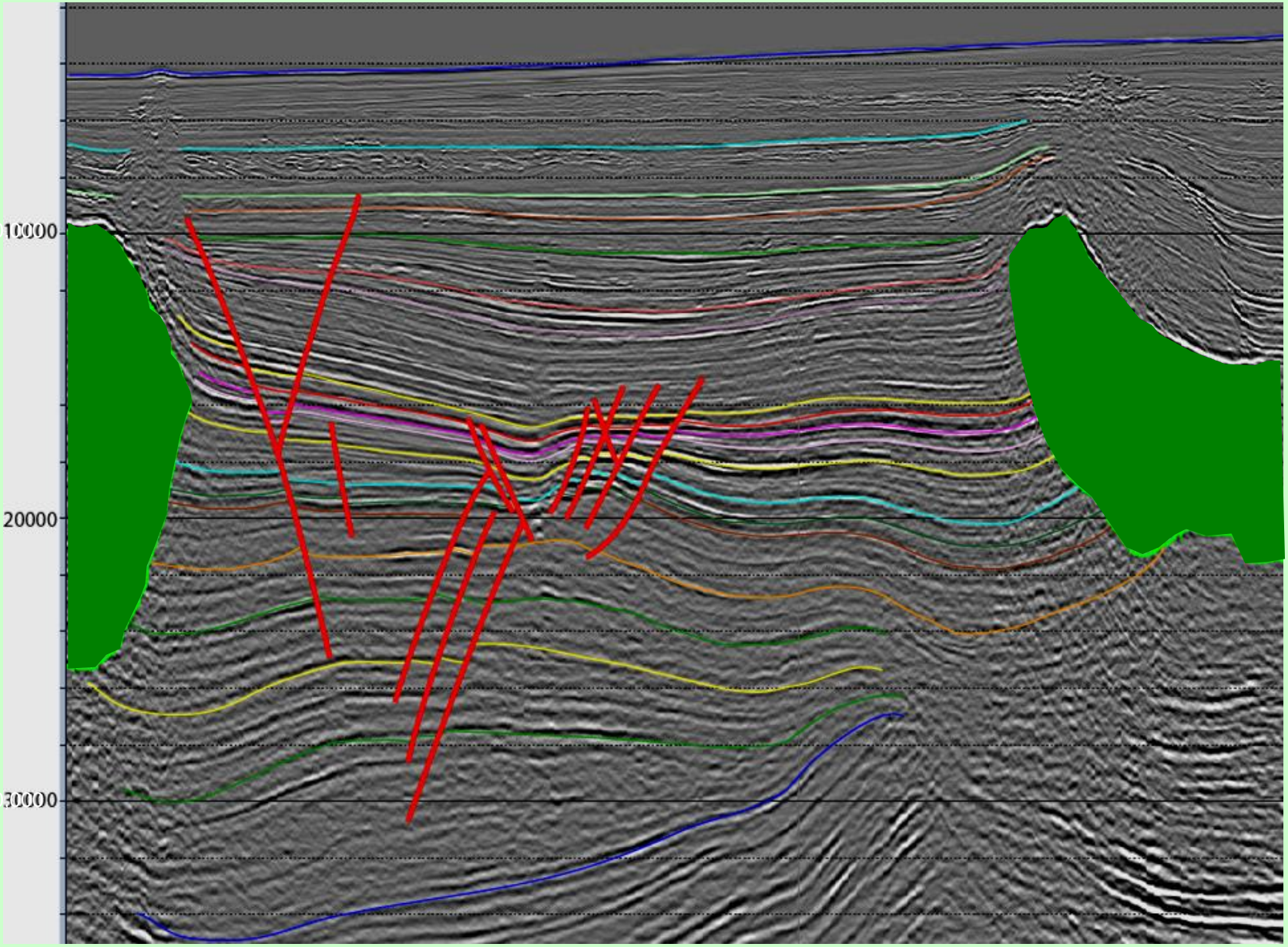


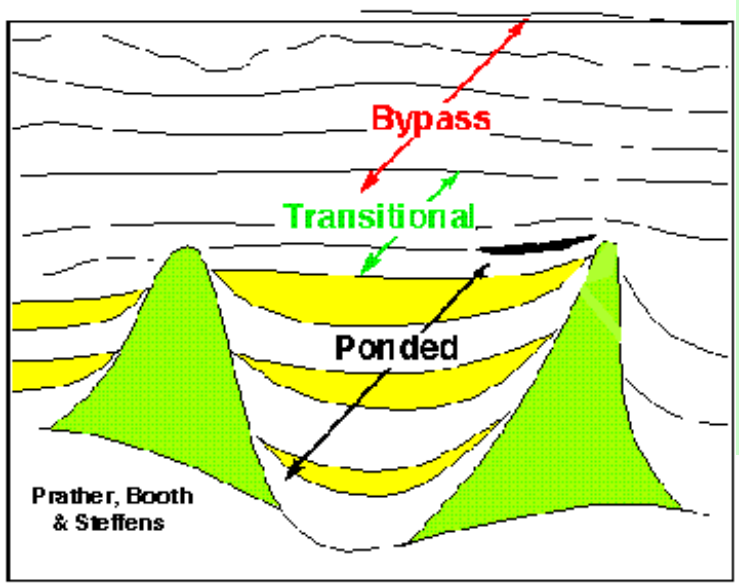
MARS MINIBASIN - GULF OF MEXICO

Lower Yellow Structure

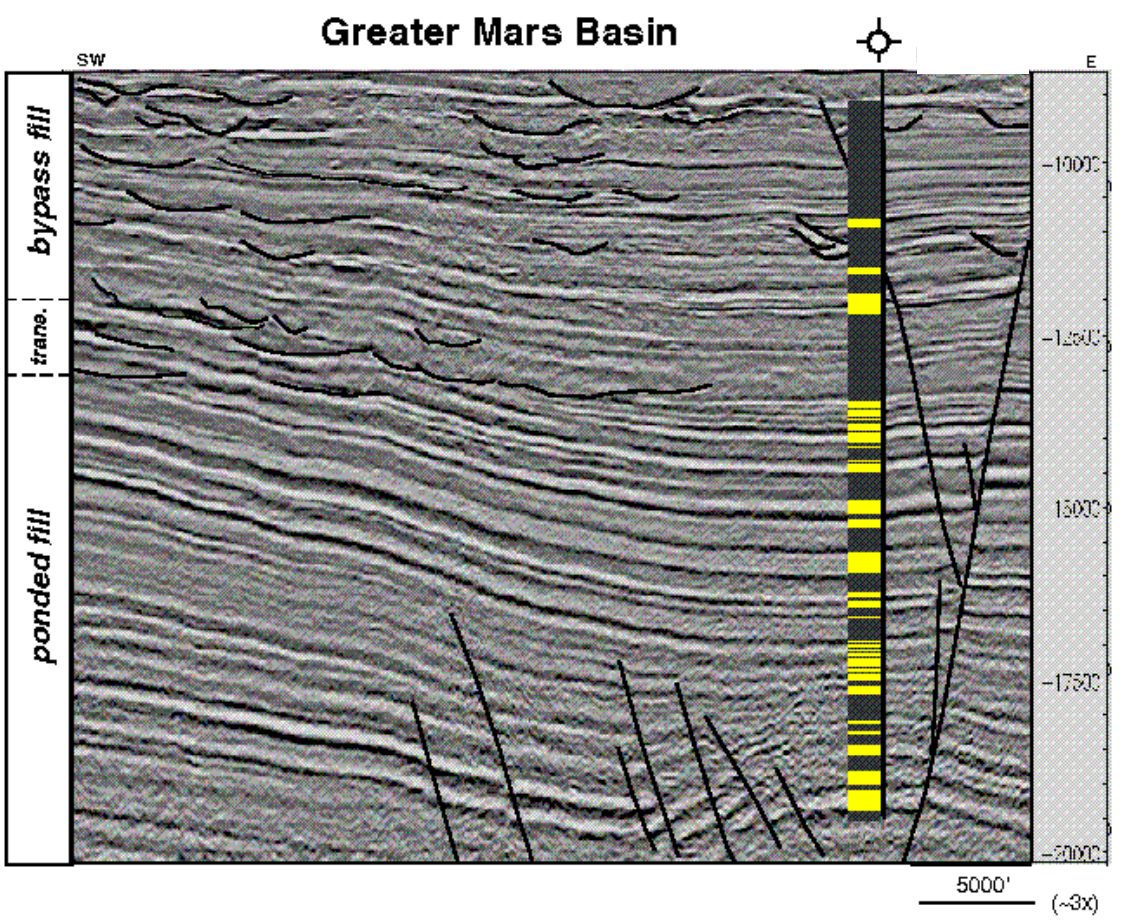


GULF OF MEXICO - MARS MINIBASIN

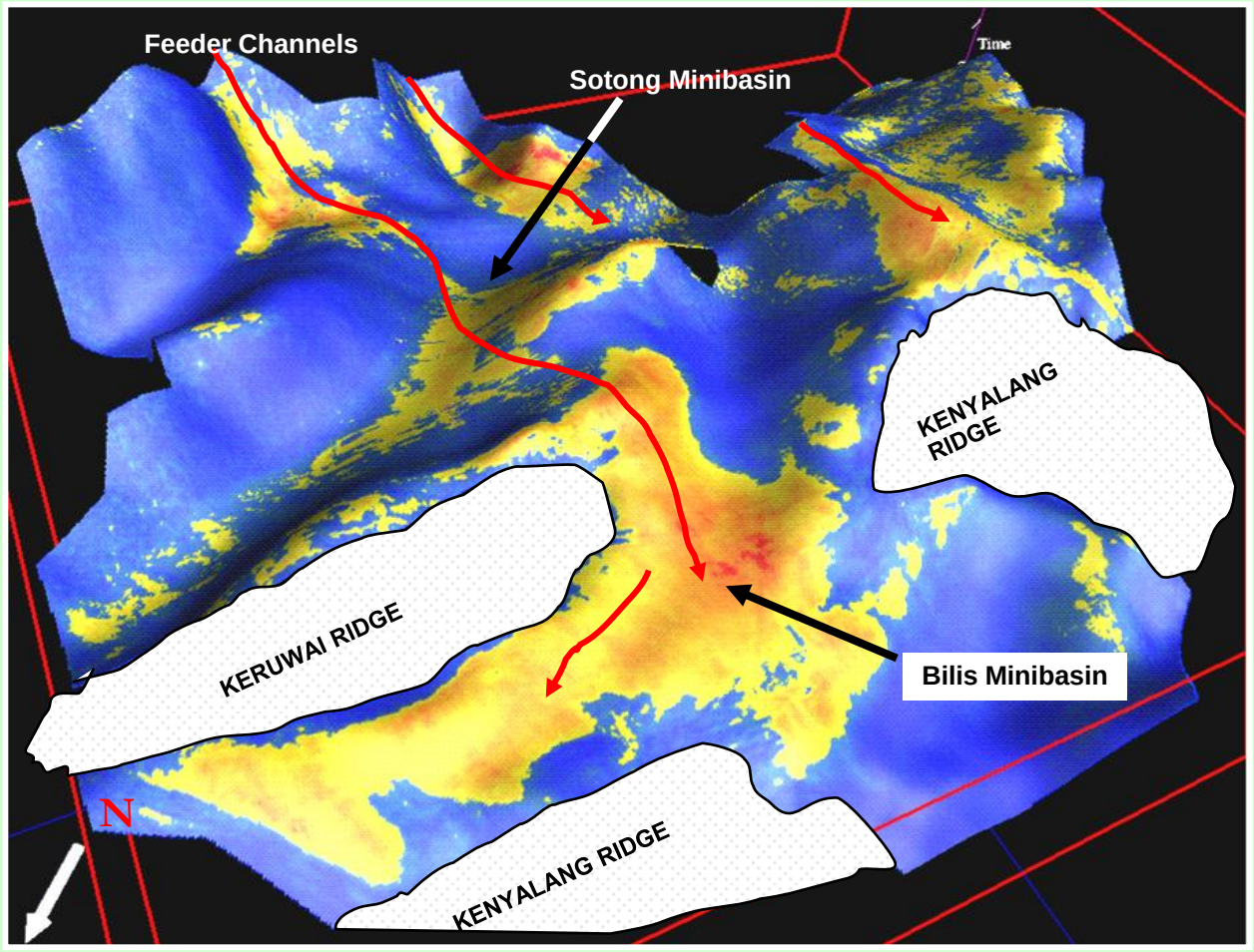


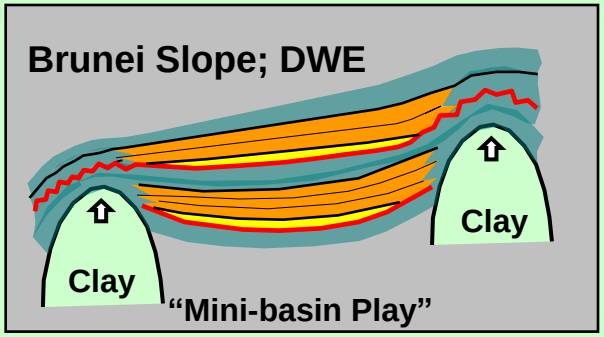


Ponded and Unconfined Turbidite Systems in GoM Minibasins



MINIBASINS DEEP WATER NW BORNEO





*** 3D view from the Northwest: 3D AvO attribute map overlain on structural of event 1b level.**

MINI-BASINS

- Large number of stacked reservoir/seal packages
- Ponded sheet sands common reservoir-type
- Updip pinch-out traps against salt/shale flanks, common stratigraphic component
- Small closures, very high lead density
- Dry wells commonly related to blown traps

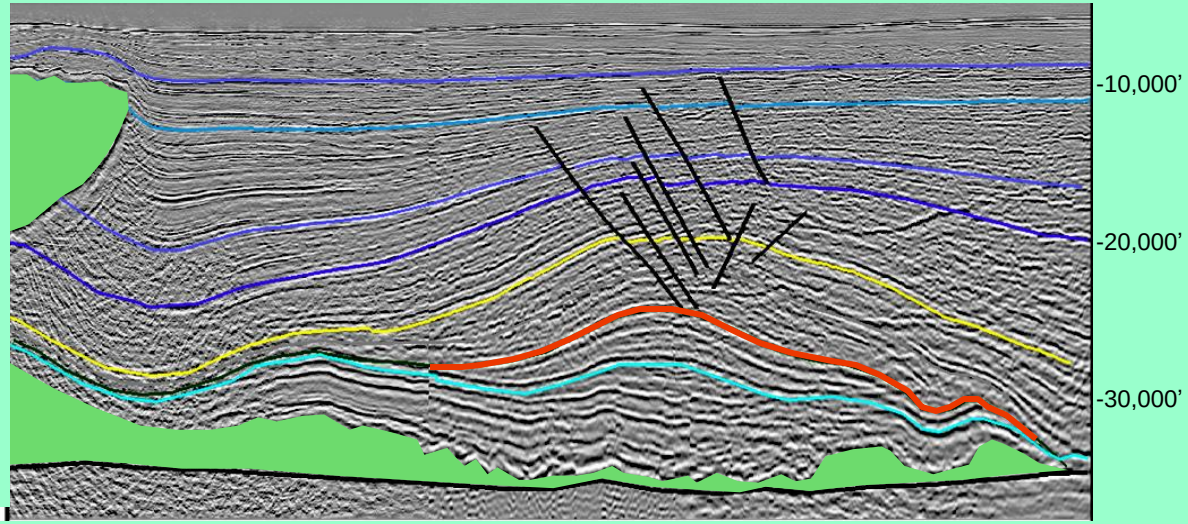
TURTLES

Turbidites in Central GoM and Brazil

Shallow marine/ continental sediments in Congo Basin and Eastern GoM

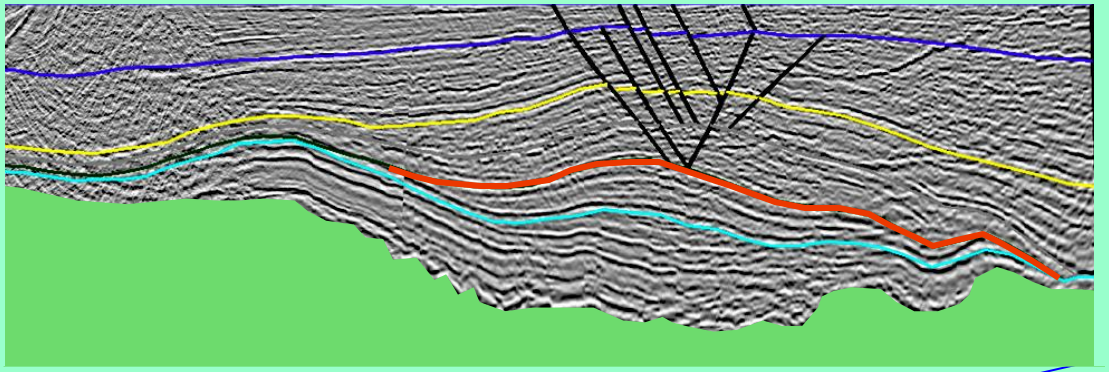
Evolution of a Turtle Structure

Present Day (~2x)



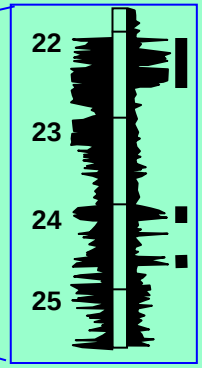
Early expulsion

Flattened on late Miocene

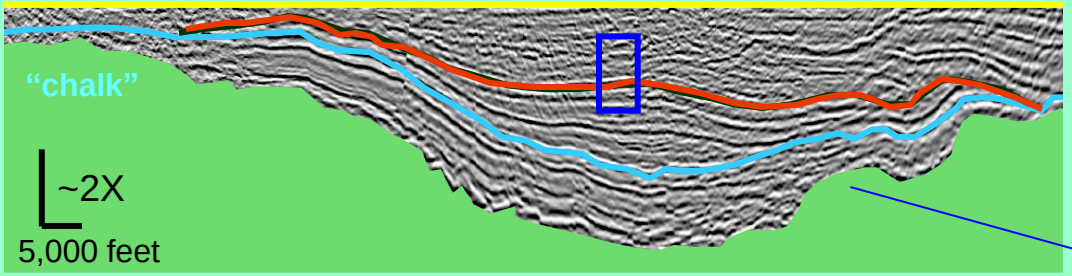


Early trap

MC 778 1 & 1ST



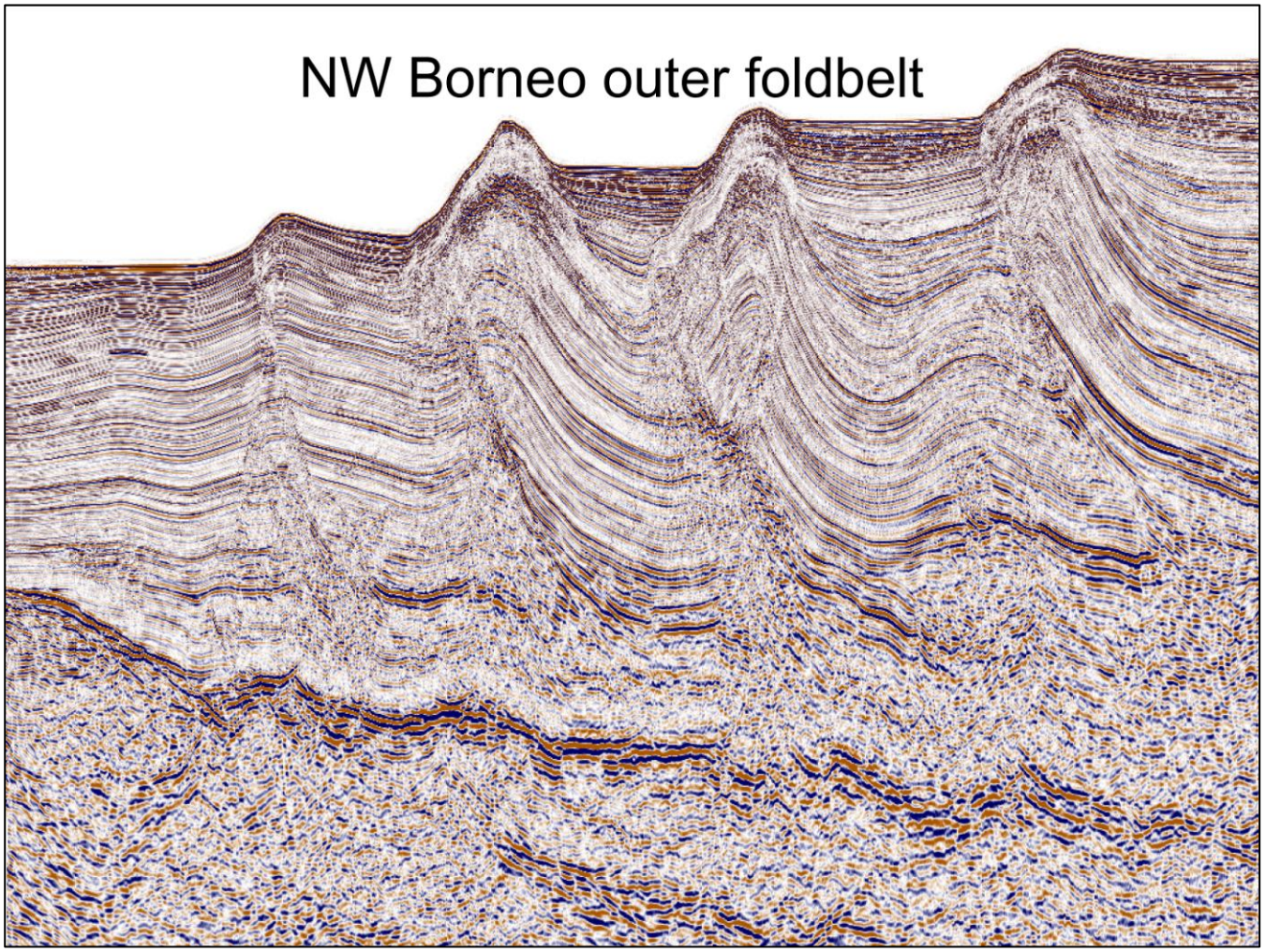
Flattened on mid Miocene (M9)



TURTLES

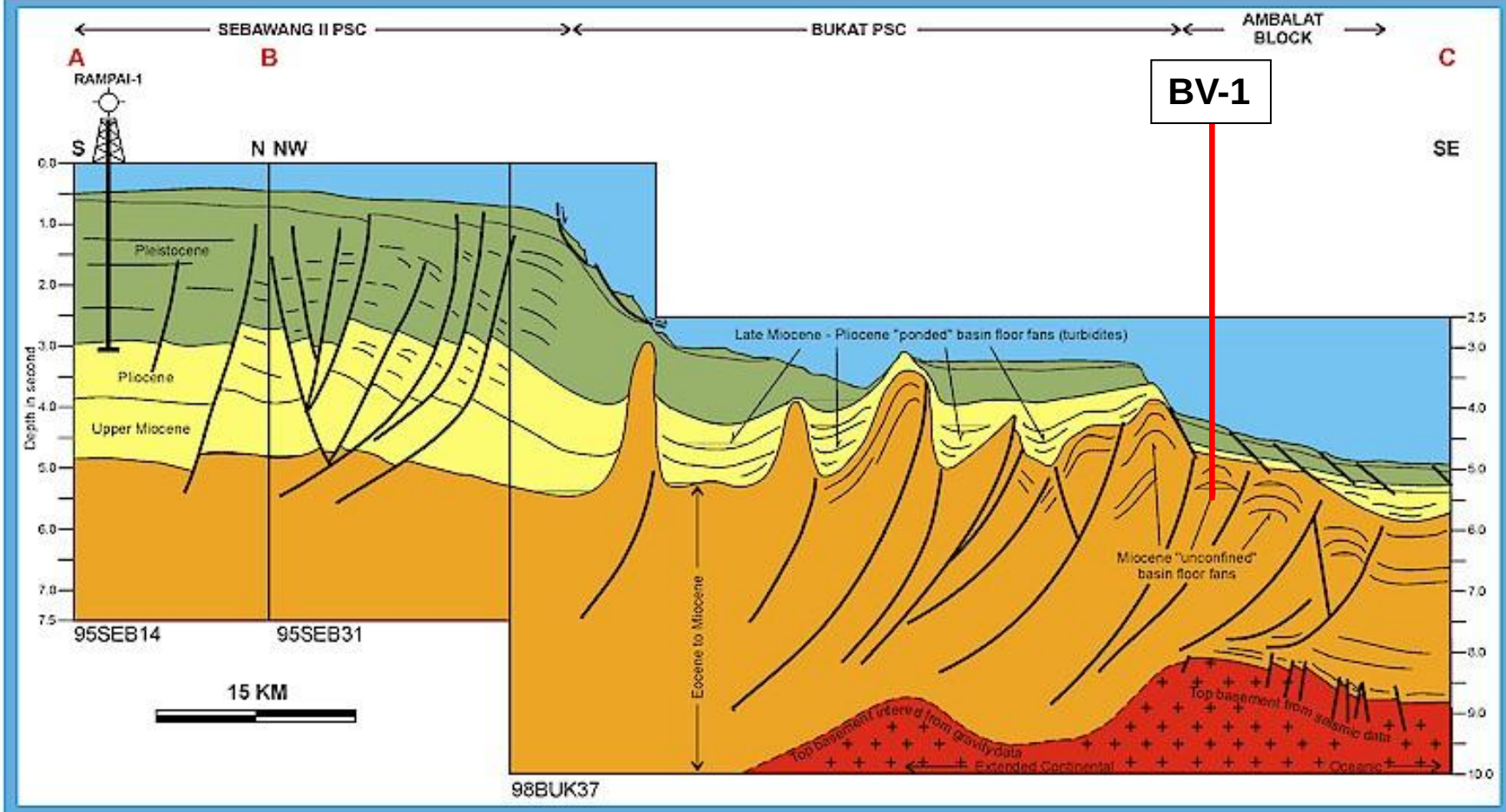
- Hydrocarbons occur:
  - Within the inverted depocenters (A)
  - Above the inverted depocenters (B)
- Reservoir extent in (A) probably sheet-like
- Reservoir extent in (B) mostly channelized
- Very large closures, medium lead density
- Turtles form in salt-floored basins only

OUTER FOLDS

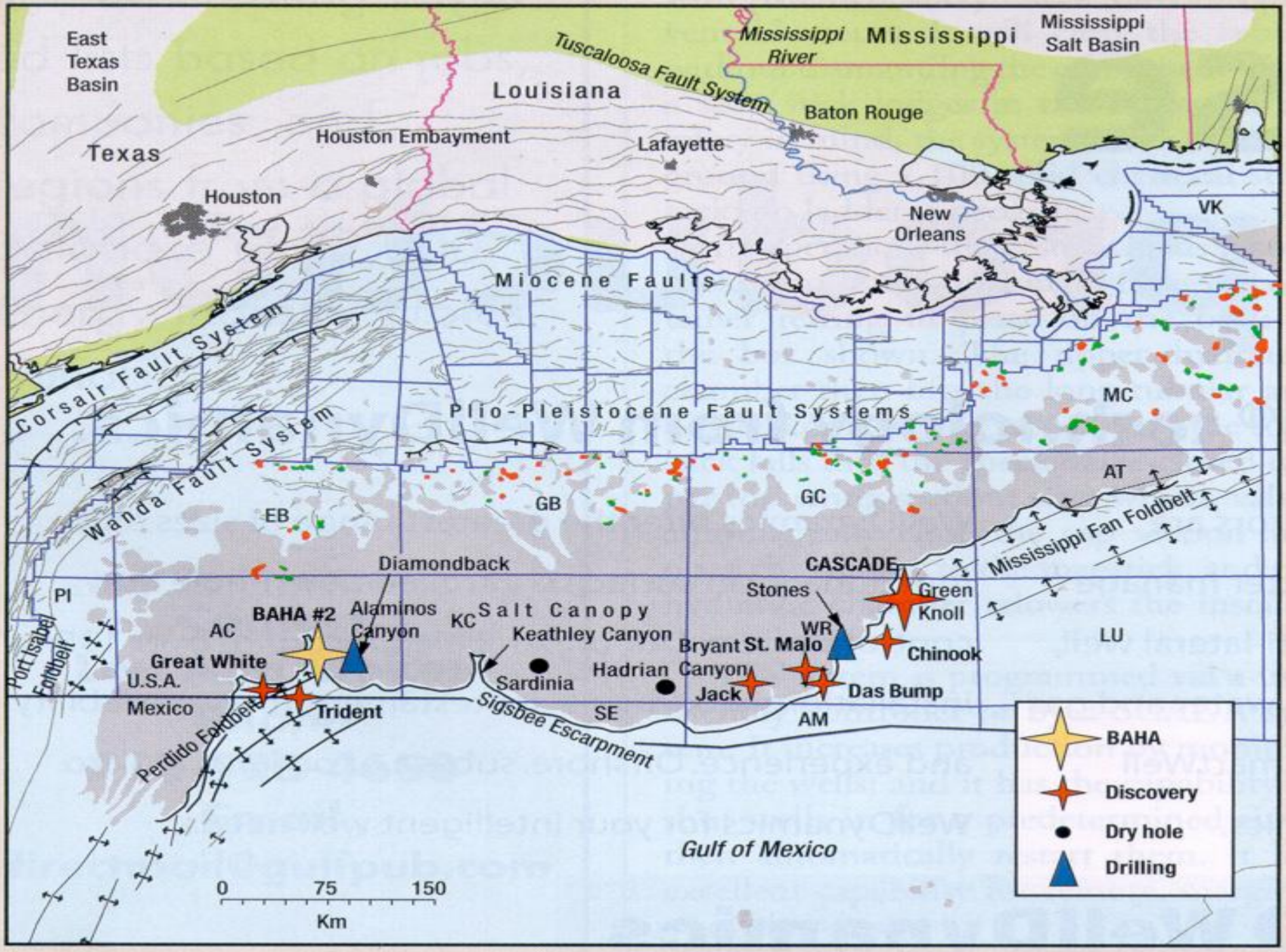


Presenter's notes: These are thrust-bound anticlines offshore NW Borneo which are being actively explored. Note the ongoing folding as demonstrated by the deformation of the seafloor. Because of active deformation there is a high risk that hydrocarbons may leak out of these traps.

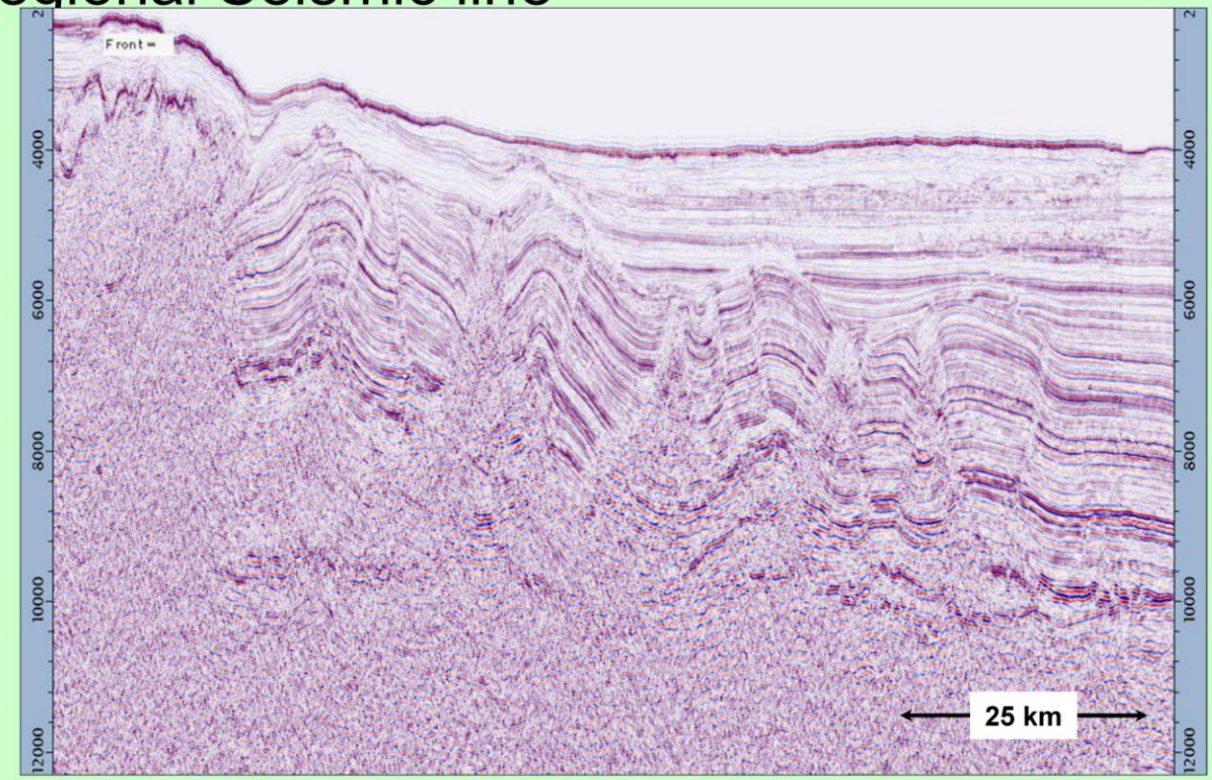
TARAKAN BASIN
SCHEMATIC GEOLOGICAL CROSS-SECTION (SOUTHERN PART OF BASIN)



EPD:\DEEPWATER\TARAKAN\BUKAT\BUK1215D.COR, 3 Feb 1999

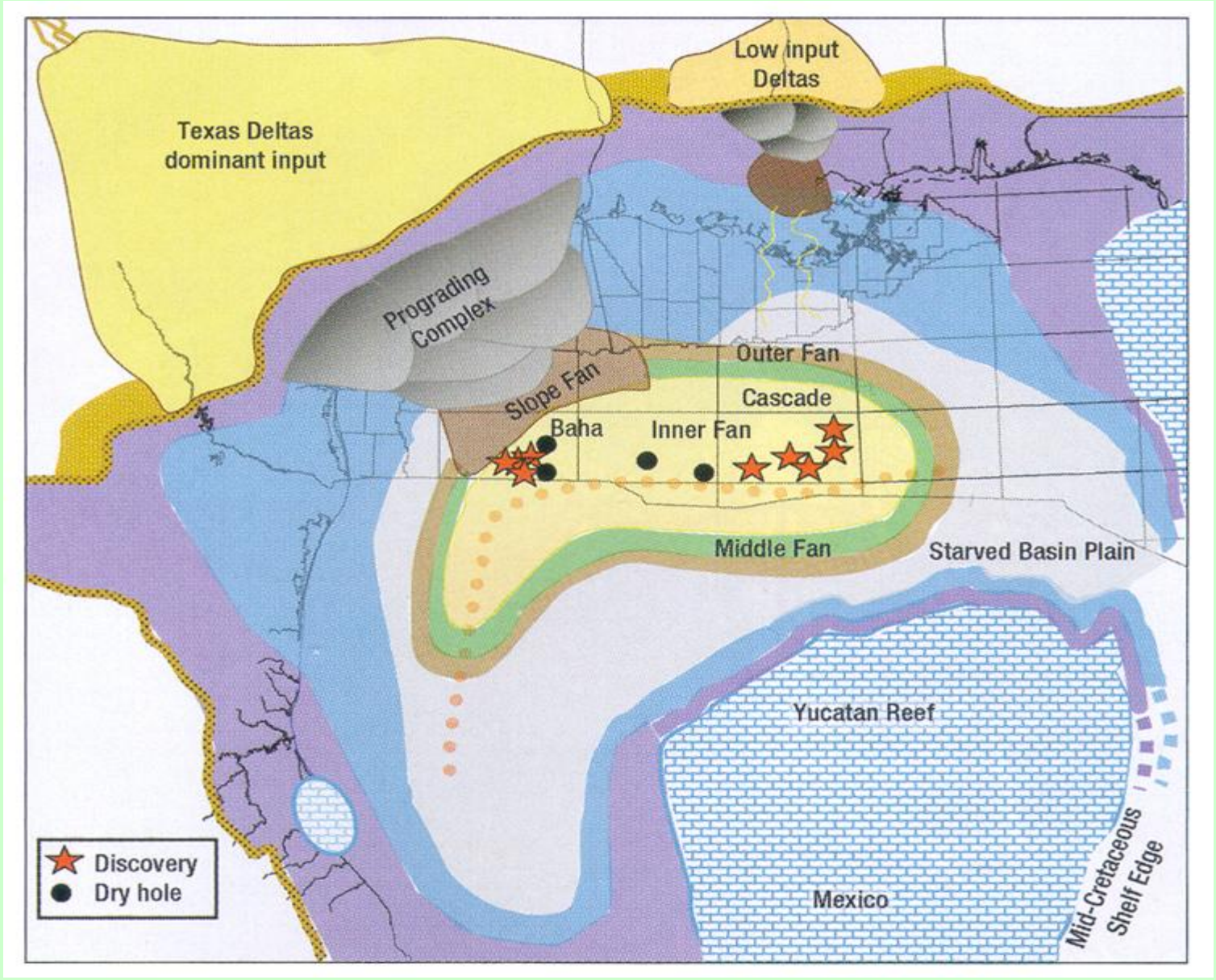

East Texas Basin
Texas
Louisiana
Mississippi River
Mississippi
Mississippi Salt Basin
Tuscaloosa Fault System
Baton Rouge
Houston Embayment
Lafayette
Houston
New Orleans
VK
Miocene Faults
Corsair Fault System
Wanda Fault System
Plio-Pleistocene Fault Systems
MC
AT
GB
GC
EB
Mississippi Fan Foldbelt
Diamondback
CASCADE
Stones
Green Knoll
PI
BAHA #2
Alaminos Canyon
KC
Salt Canopy
Keathley Canyon
WR
LU
AC
Bryant Canyon
St. Malo
Chinook
Port Isabel Foldbelt
Great White
U.S.A.
Mexico
Sardinia
Hadrian
Jack
Das Bump
Trident
Perdido Foldbelt
Sigsbee Escarpment
SE
AM
Gulf of Mexico
0
75
150
Km
BAHA
Discovery
Dry hole
Drilling

Perdido Foldbelt Western Gulf of Mexico: Regional Seismic line



Presenter's notes: A seismic example of the Perdido Foldbelt in the Western Gulf of Mexico. Note how the compressional folds (anticlines) are bound by thrust faults.

Wilcox Deepwater Fan, Gulf of Mexico



OUTER FOLDS

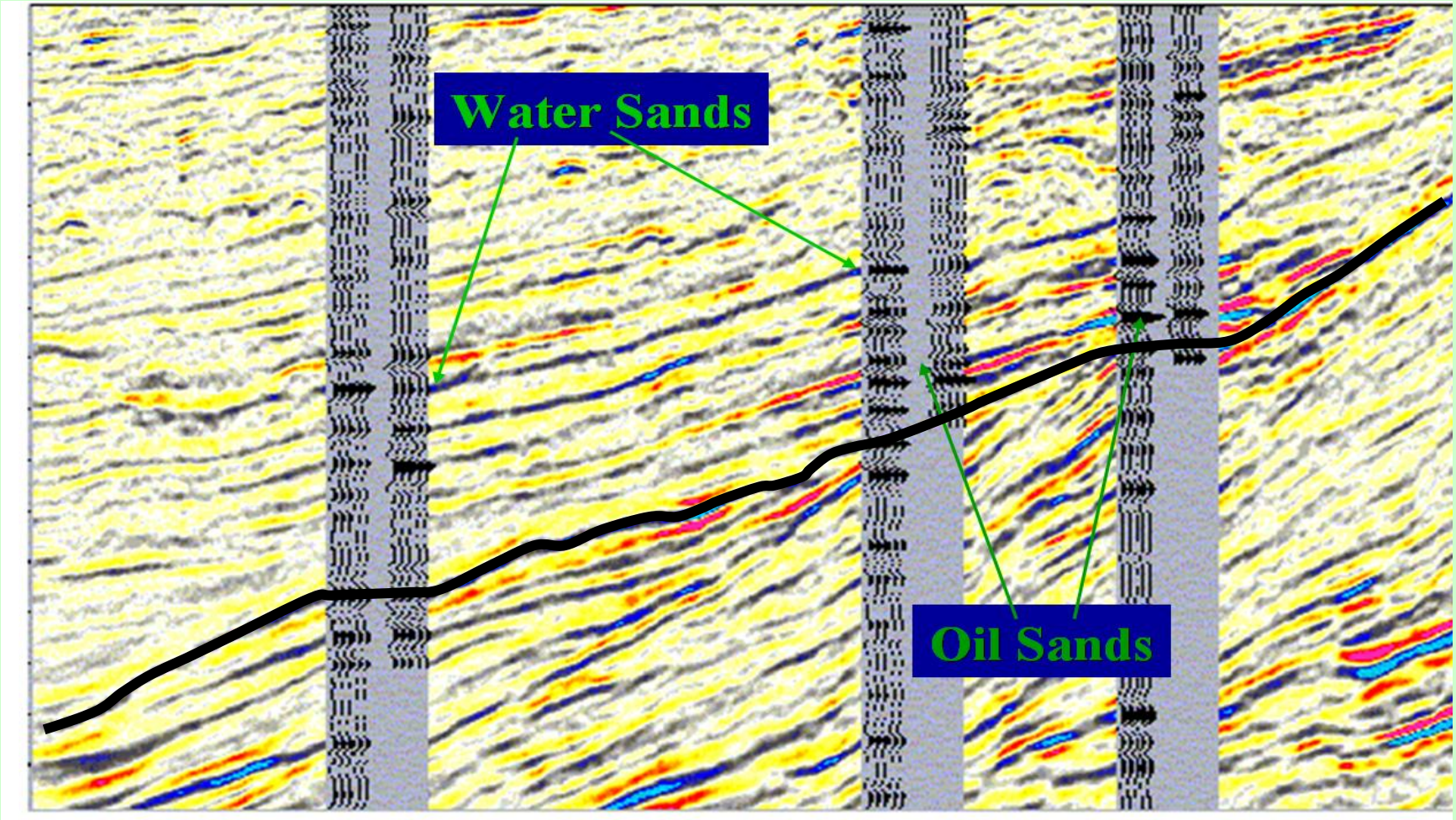
- Very limited exploration drilling so far
- Major future opportunity
- Very large closures, low density
- Basin floor fan reservoirs
- Access to a mature kitchen critical
- High risk for blown traps
- Outer Folds form downdip of major deltas and are coupled to extension updip, except in active margins where subduction plays a role as well

TURBIDITE PLAYS ON A NON MOBILE SUBSTRATE

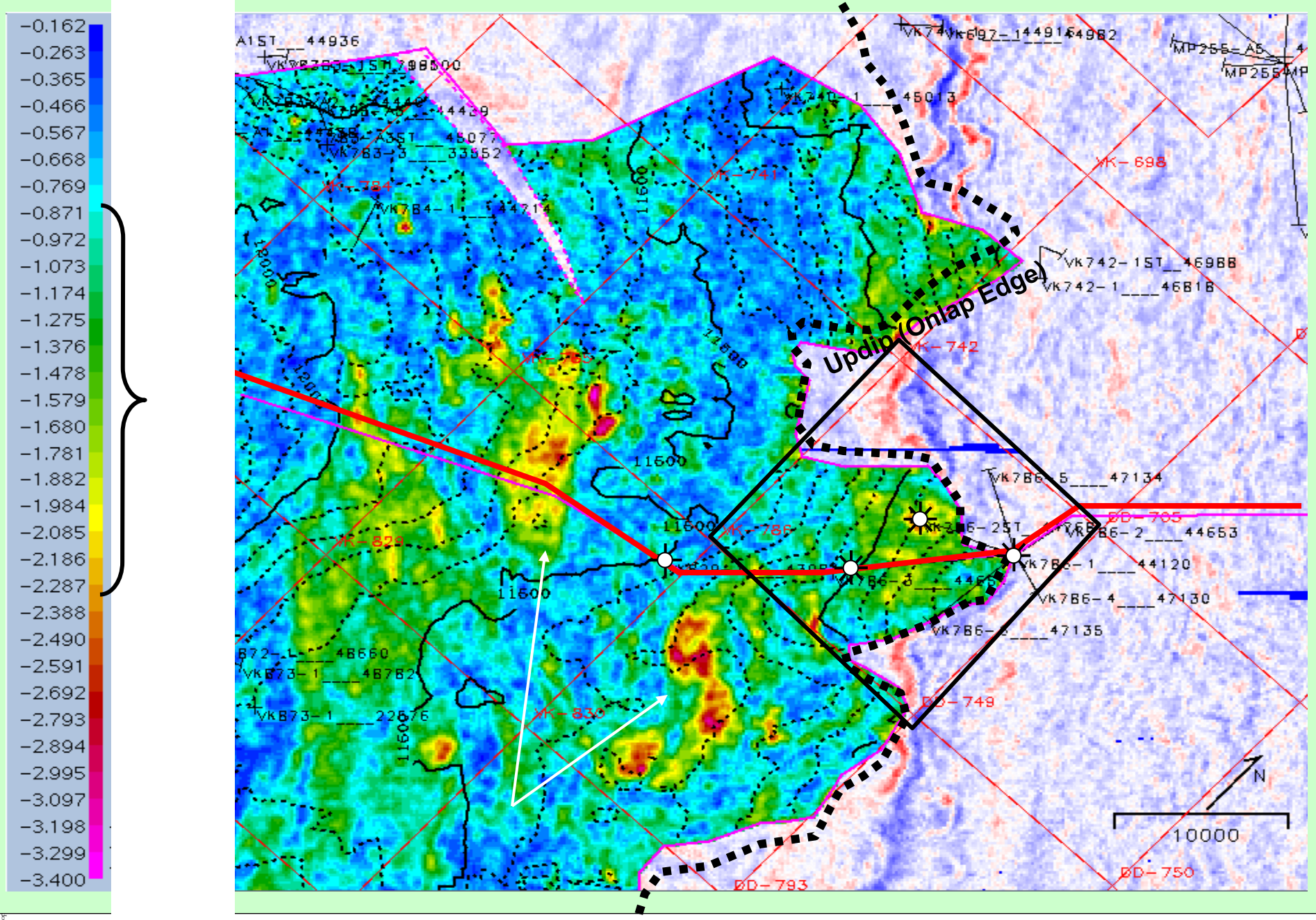
Onlaps
Pinchouts

EASTERN DEEPWATER GULF OF MEXICO ONLAP TRAP

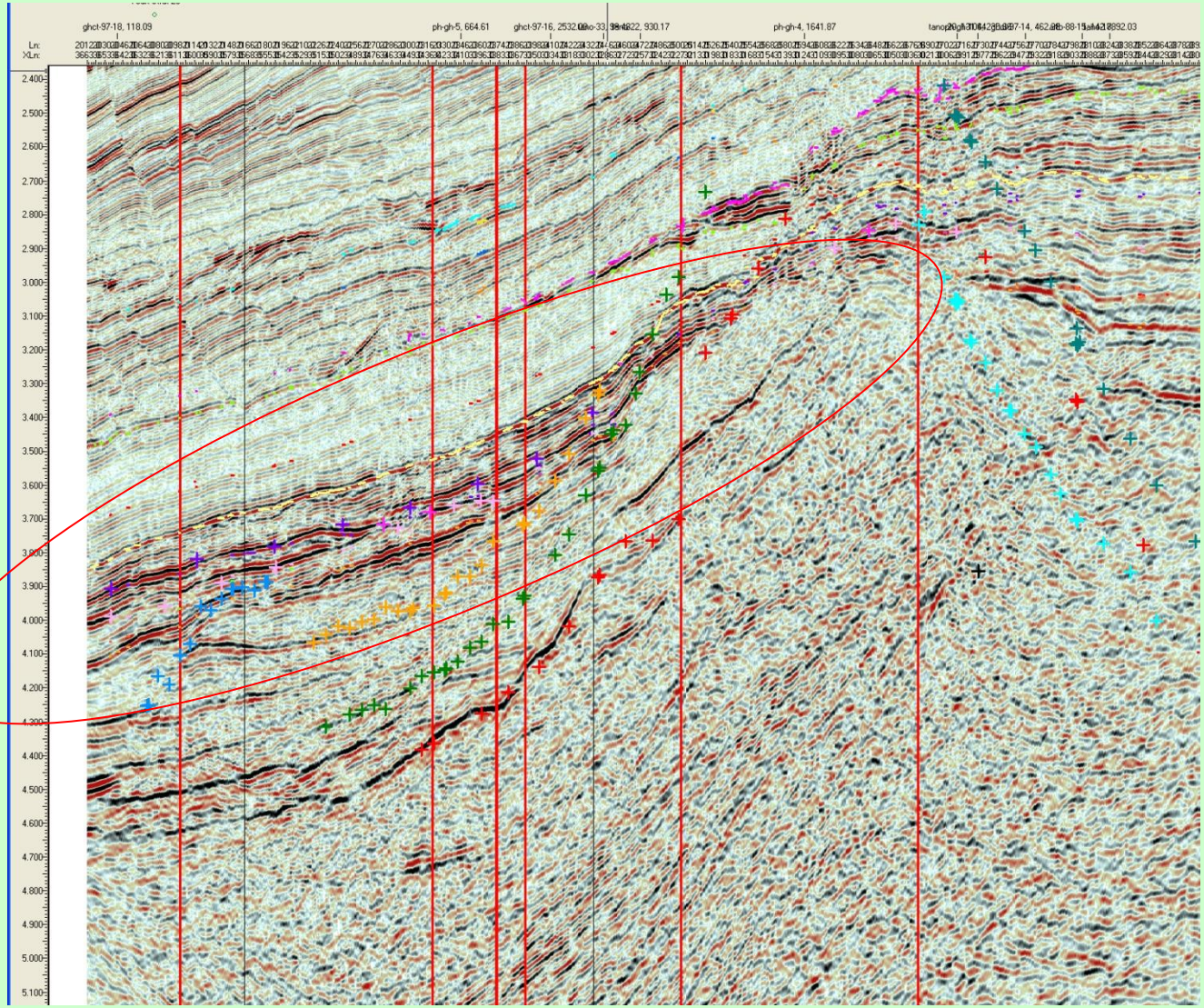
Turbidite Play (Upper Cretaceous)



EASTERN GULF OF MEXICO DEEPWATER, MAP OF ONLAP TRAPS

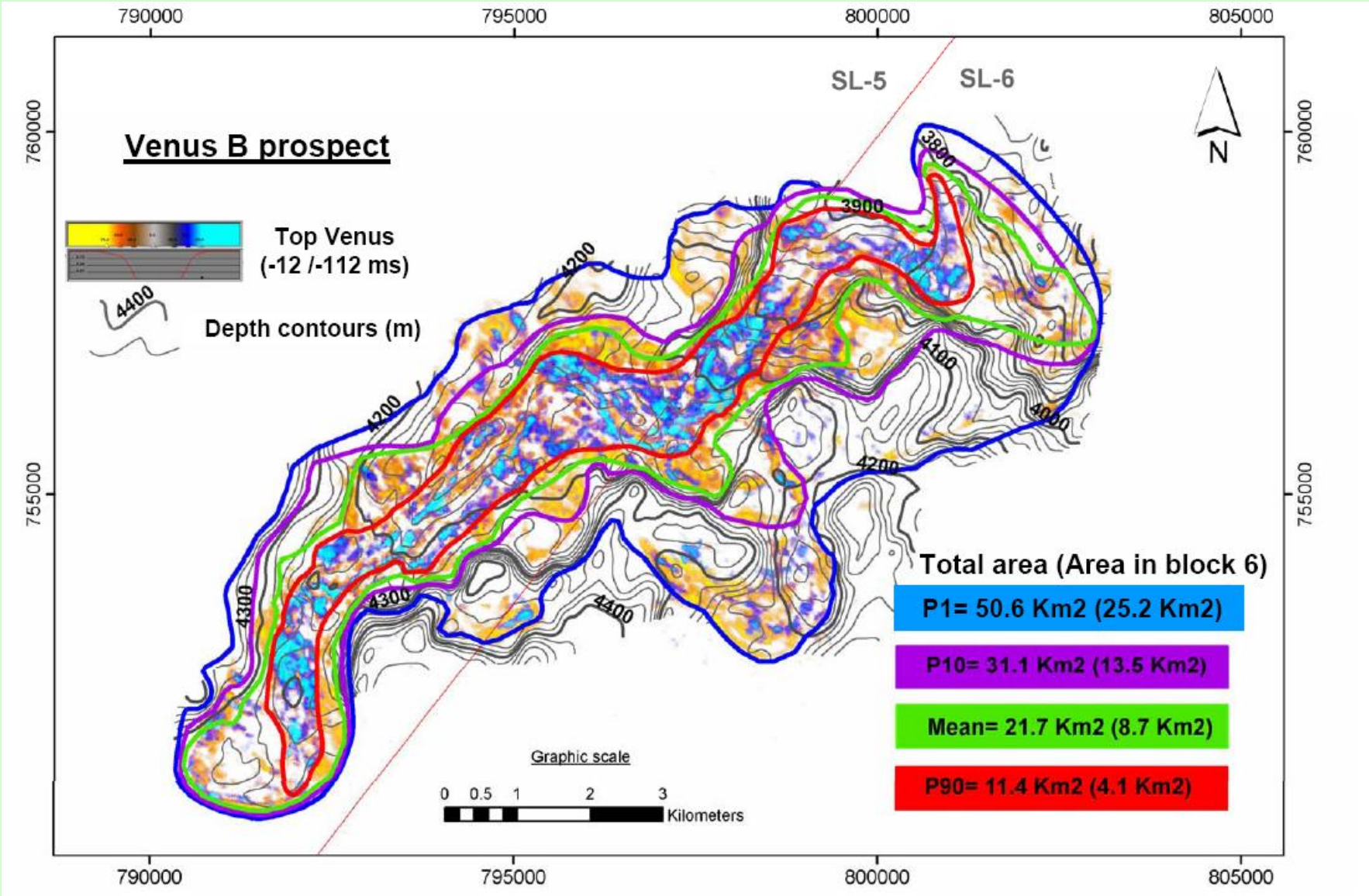


DEEPWATER GHANA, JUBILEE DISCOVERY



Clear pre-drill AVO indication

Deepwater Sierra Leone



CONCLUSIONS

- **Richest turbidite basins formed on top of mobile substrate of salt or shale**
  - **High trap density**
  - **Similar and predictible structural evolution**
- **Rapid deposition of a thick deep water clastic apron**
  - **Widespread source rock maturity**
  - **Stacked reservoir/seal packages**
- **Neogene settings characterized by "Big Rivers" supplying turbidites into large offshore depocentres**
- **Late Cretaceous and Paleogene settings characterized by multiple "Small River" systems**
- **Outer Foldbelts an important frontier, but situated in great water depth**
- **Basins without mobile substrate have a low trap density, a complex stratigraphic configuration, but are** relatively underexplored