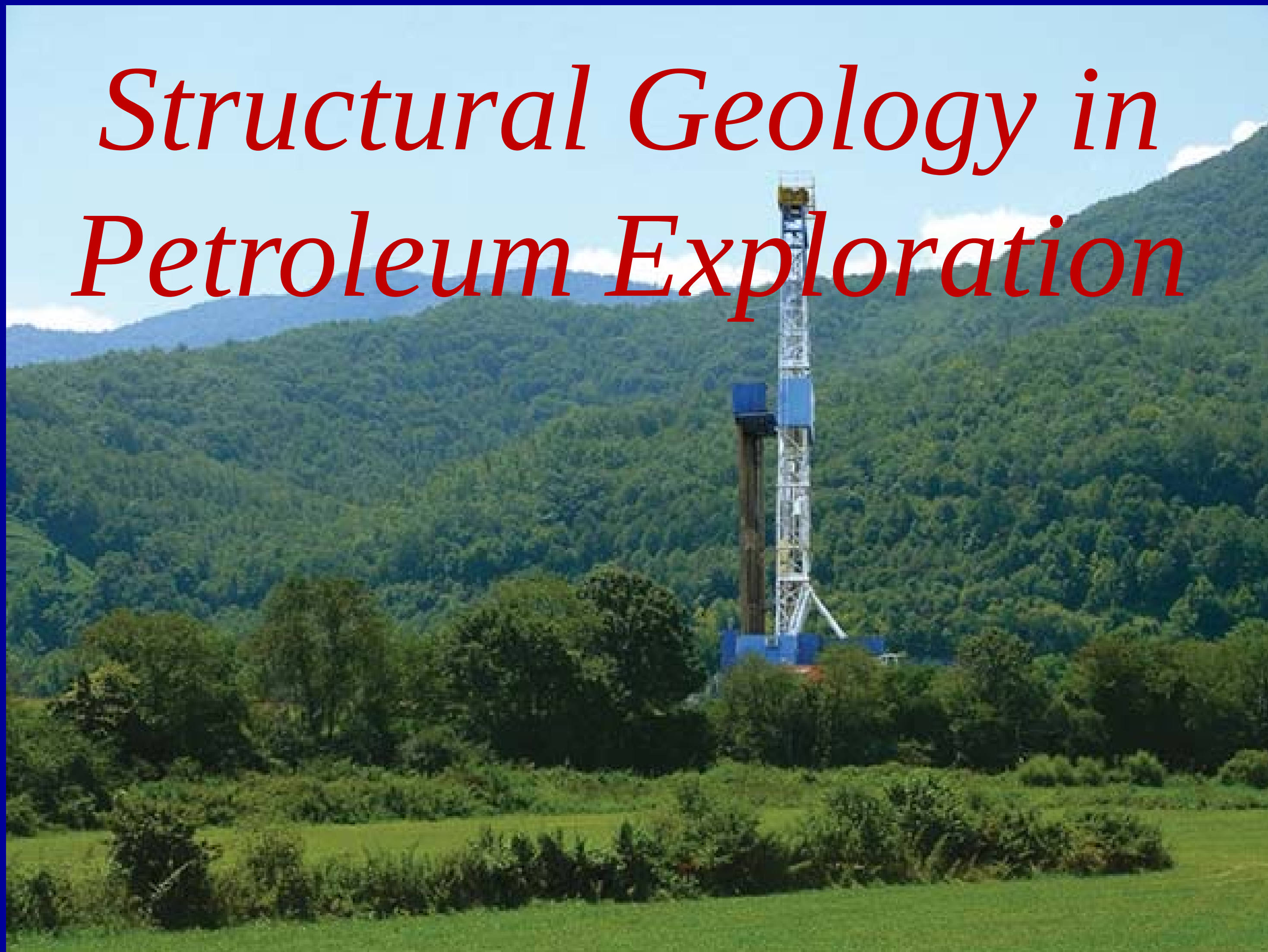
Structural Geology in Petroleum Exploration



Topics:

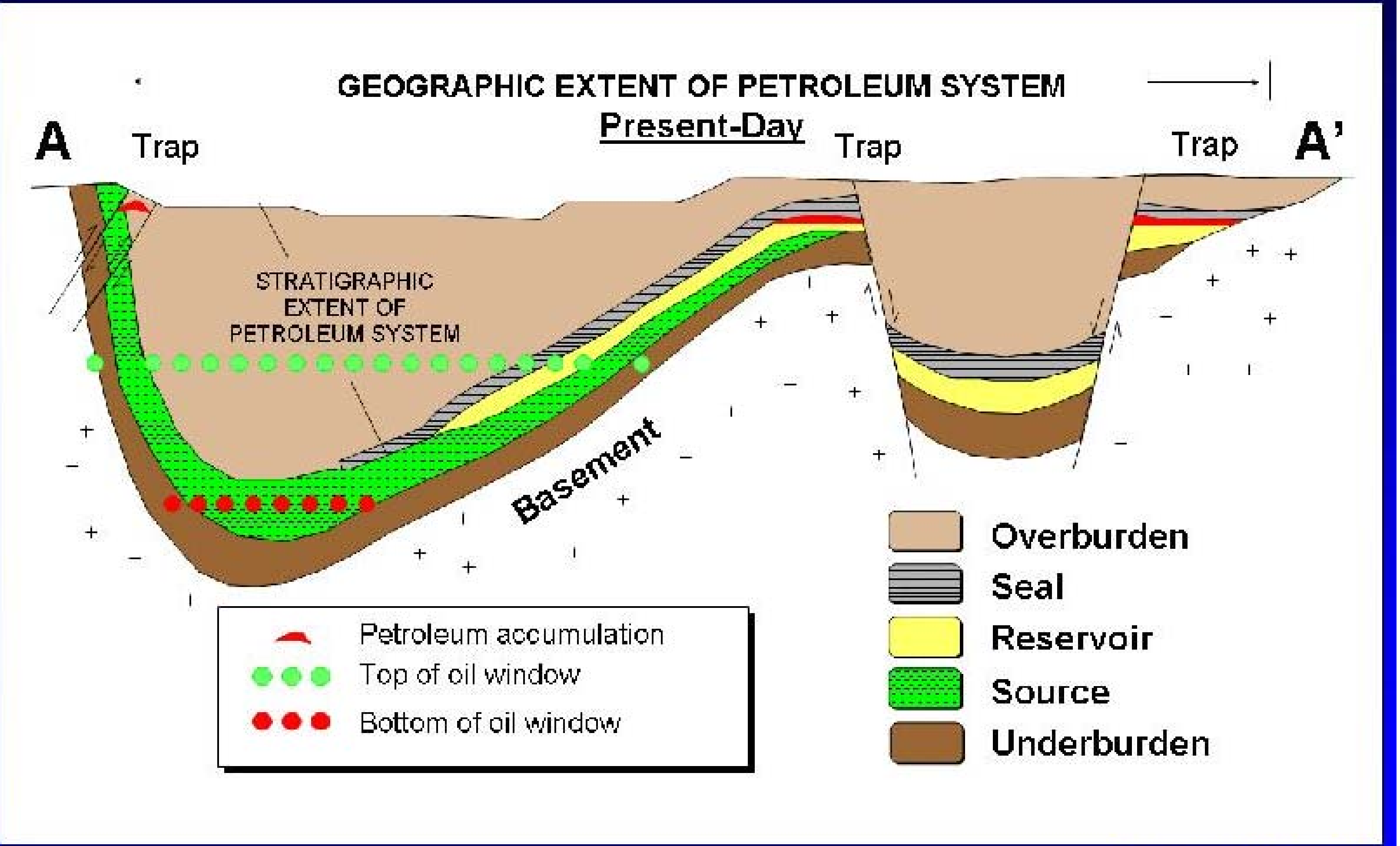
- Petroleum System
- Traps
- Exploration Methods (seismic)
- Maui Field Example
- Salt Tectonics

- Reading:
  1. Outline in website
  2. Pdf file: *Geology for Petroleum Exploration, Drilling, and Production* by Norman J. Hyne, 1984, pages 173-197.

Factors required to make a conventional Oil Deposit

- A Sedimentary Basin with:
  - Source rock- rich in organic matter
  - Burial heating $\Rightarrow$ maturation
  - Reservoir rock- porous and permeable
  - Trap-
    - structural trap
    - stratigraphic trap

Present-Day Petroleum System



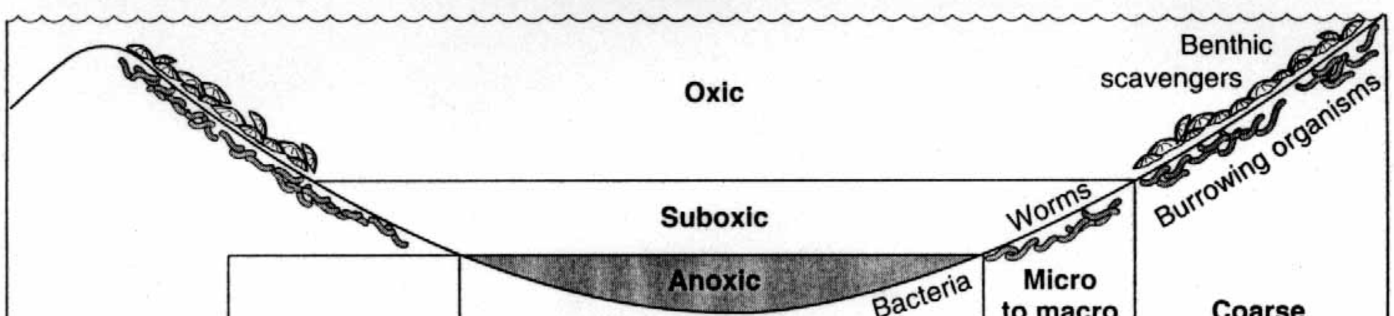
Magoon and Dow, 1994

Oil Exploration Strategy:

- Find the Traps
- The most common traps are structures
- Can’t see the oil ahead of the drill
- So exploration often targets the structures in hopes of finding oil

Origin of Petroleum

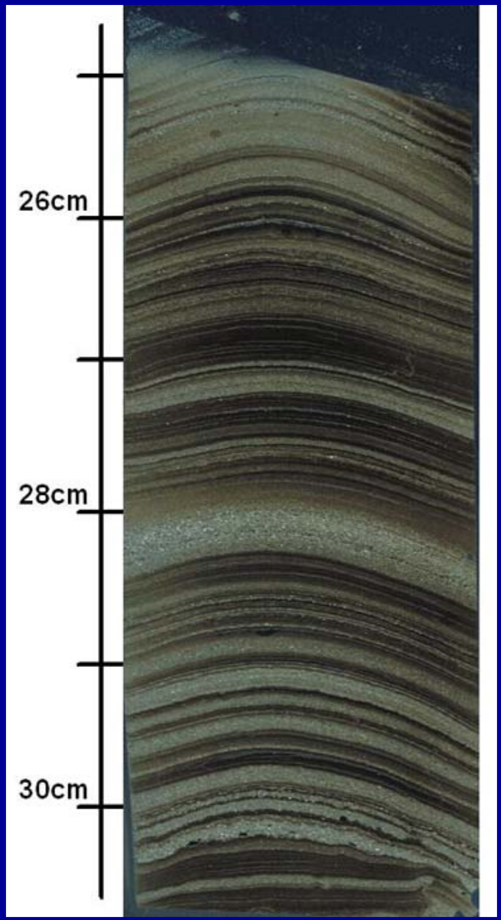
- Oil forms from the decay and transformation of dead organisms (algae) buried in sedimentary rocks



Sediment	Laminated, no bioturbation	Micro to macro burrowed	Coarse bioturbation
% Total Organic Content	3 to 20	1 to 3	0.05 to 1
H/C of OM	1.6	1.2	0.8
OM type	I and II	II – III	III – IV

Source Rocks

- Black organic-rich marine shales
- Organic matter is preserved in low-oxygen water
- Restricted marine basins and zones were water rises from the deep

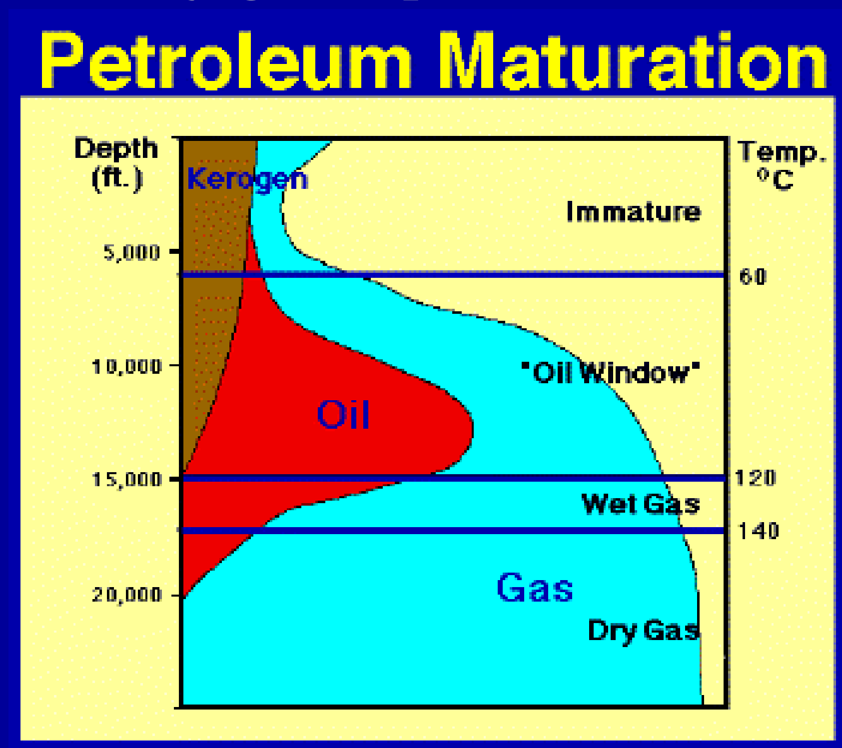


Maturation of Organic Matter

At about 60º C transformation of kerogen begins

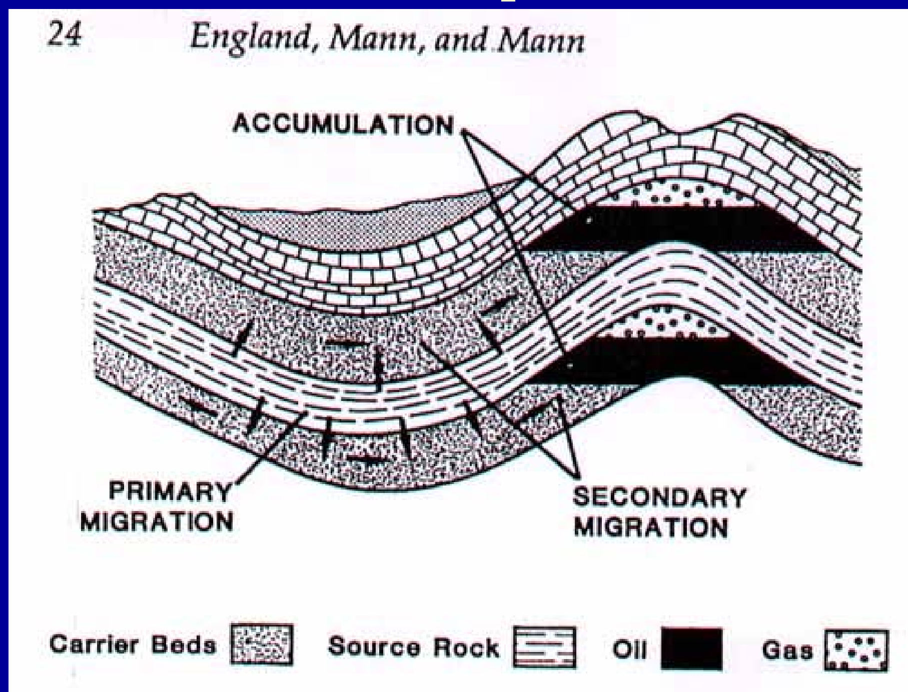
- Liquid hydrocarbons begin to form

◆ Above 140º C only gas is produced

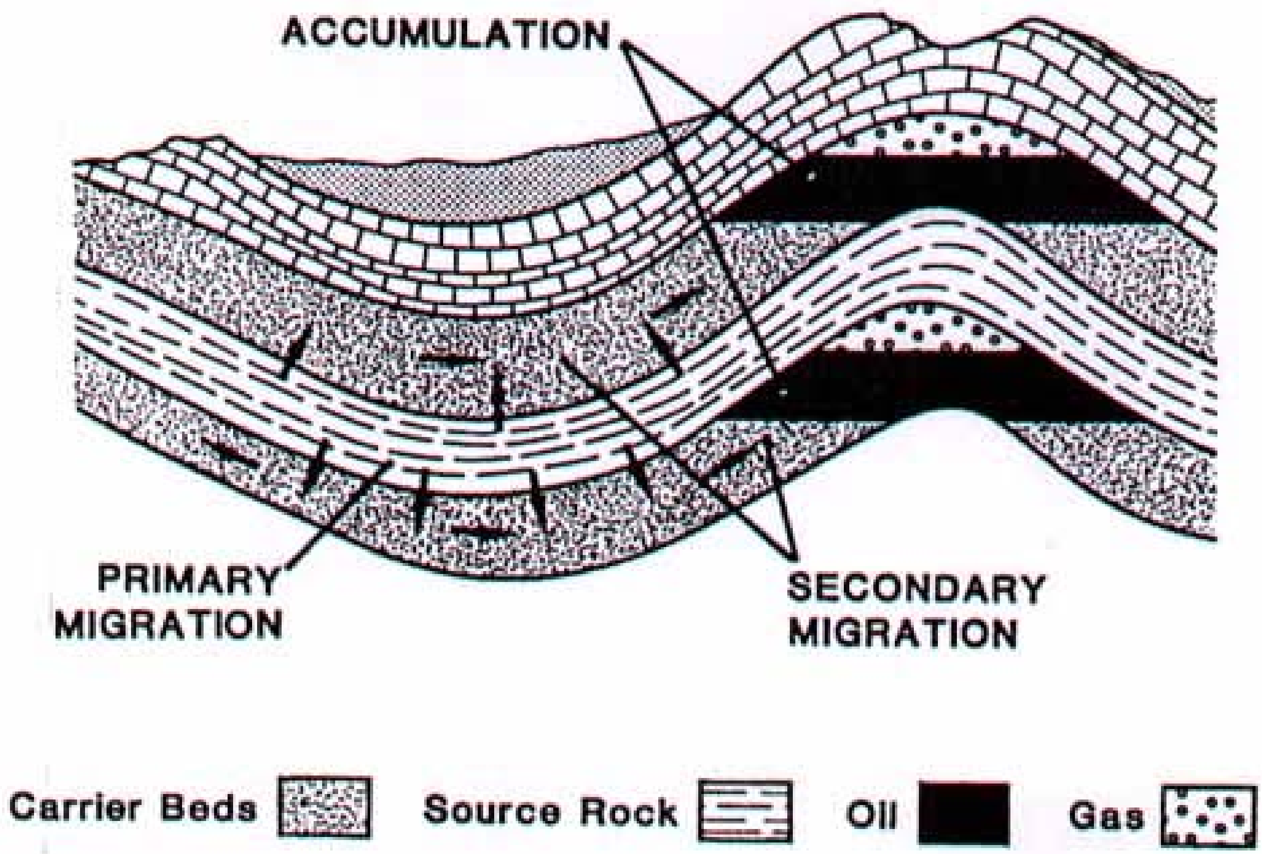


Migration of oil

- Oil is less dense than water
- Oil will move up by buoyancy
- Oil needs a permeable bed to move
- It will stop when it reaches an impermeable bed



Migration


ACCUMULATION
PRIMARY MIGRATION
SECONDARY MIGRATION
Carrier Beds
Source Rock
Oil
Gas

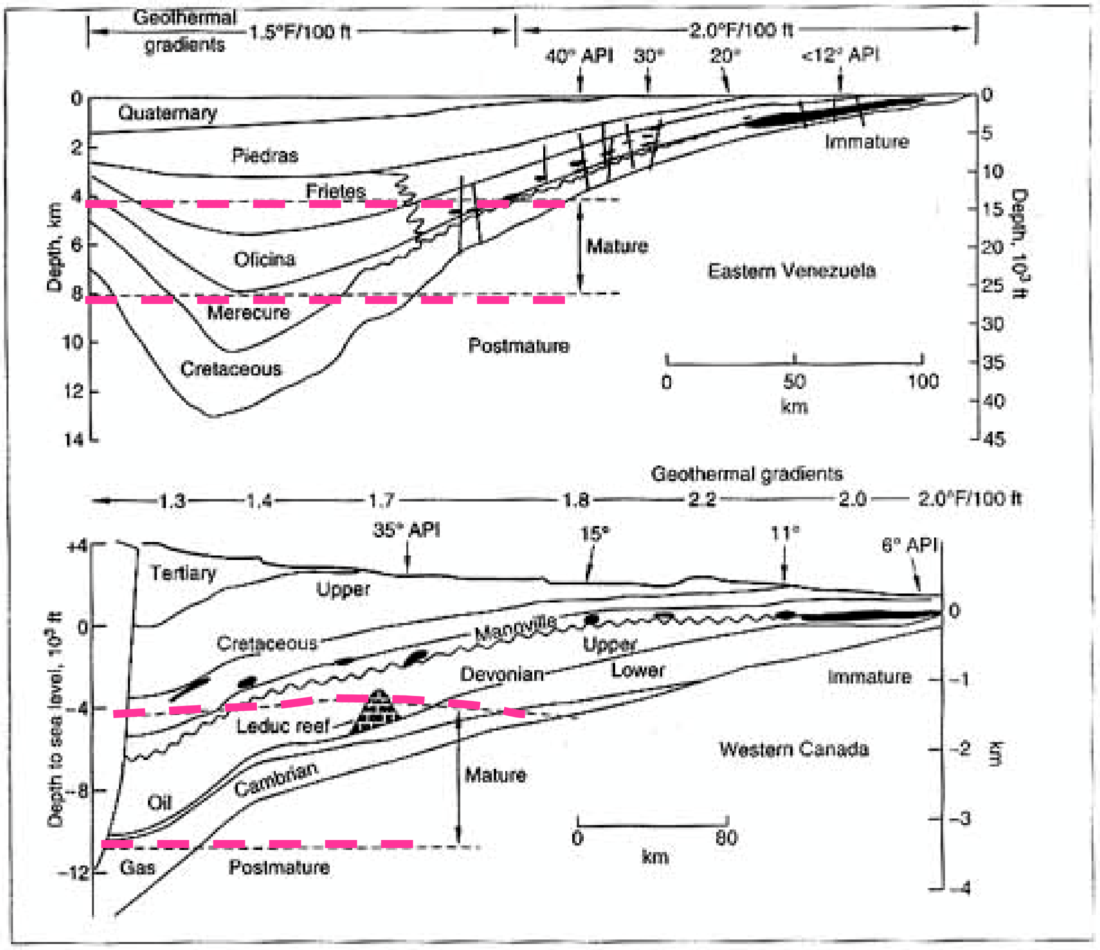


Figure 8-18

Long-distance lateral migration in the Eastern Venezuelan and Western Canada Basins. The oil-generation windows are labeled mature. [Demaison 1977; Roadifer 1987]

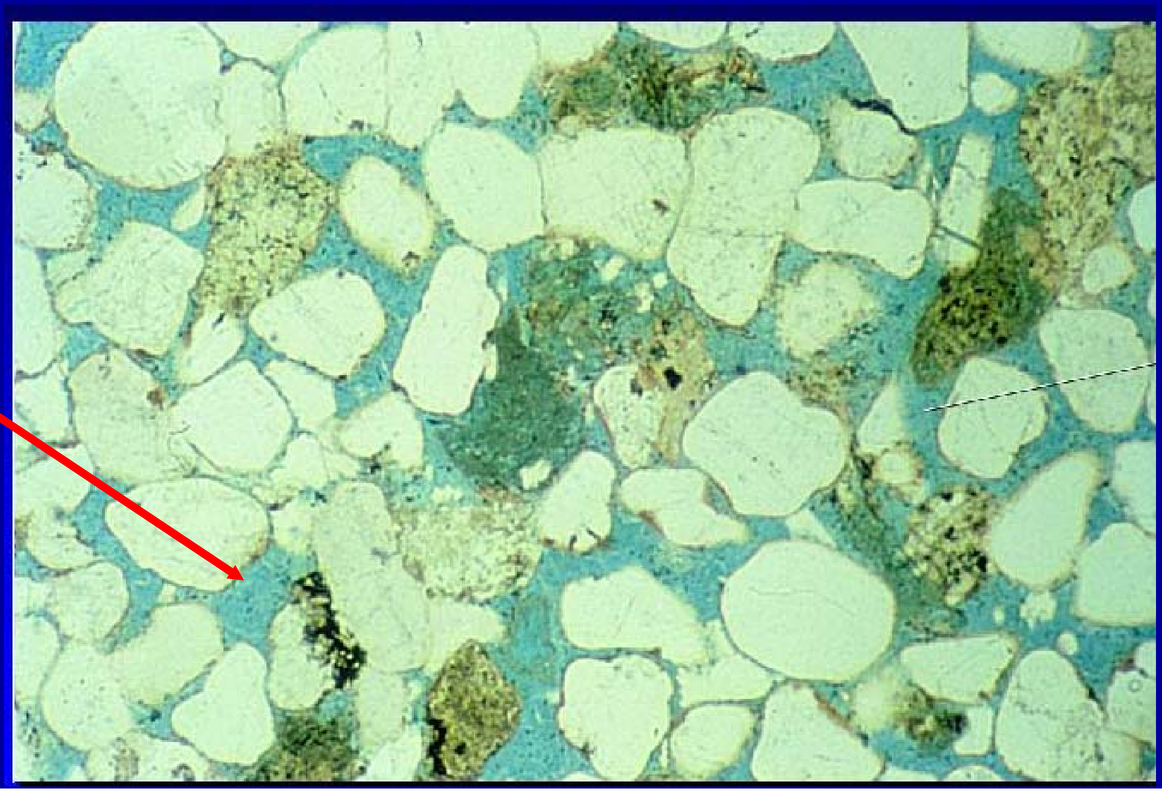
Eastern Venezuela

Western Canada

Oil Reservoirs

- Permeable reservoir bed
- Impermeable seal

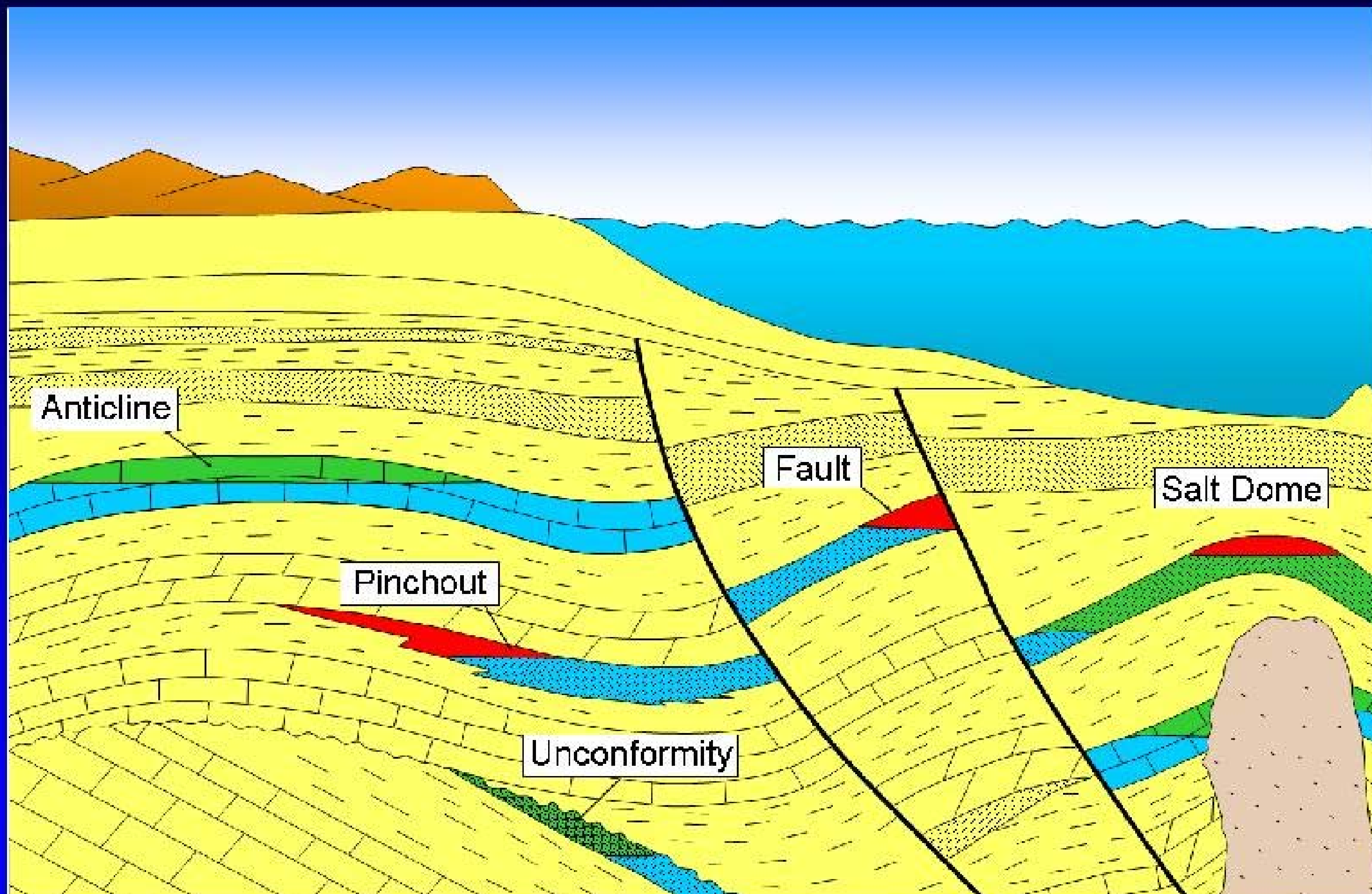
Sandstone



Porosity

Open space!

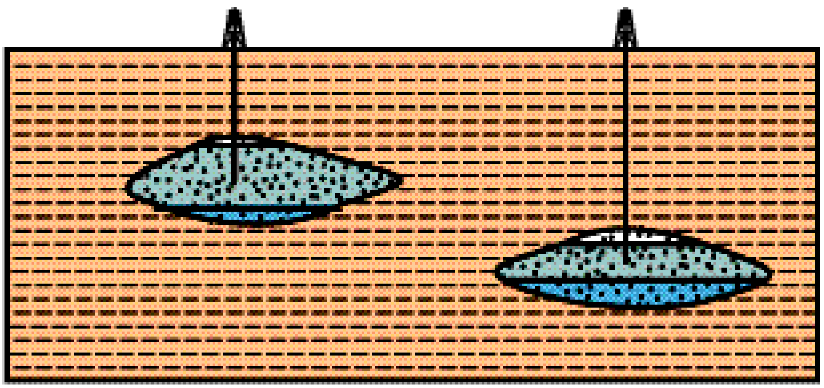
Hydrocarbon Trap Types



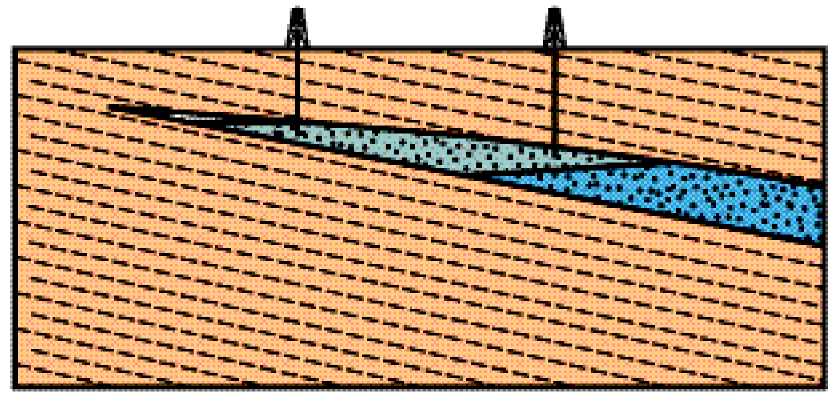
American Petroleum Institute, 1986

JMA

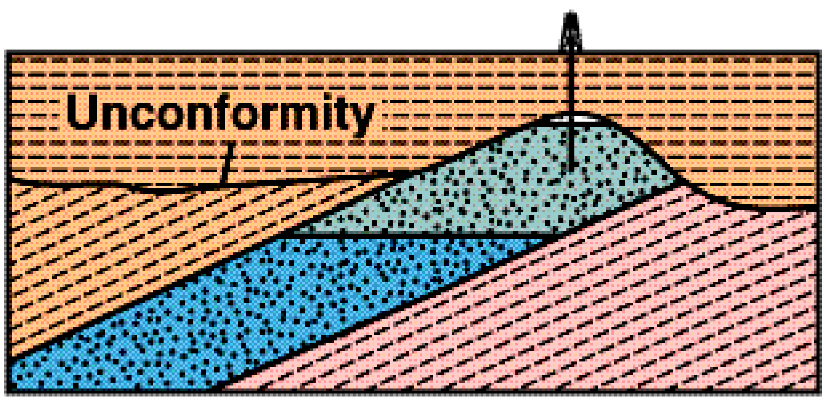
Stratigraphic Oil Traps



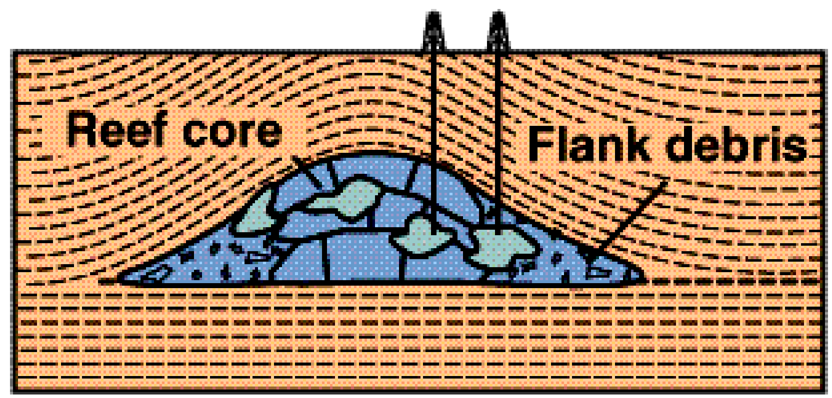
D Sandstone lenses



E Sandstone pinchout



F Unconformity



G Reef (a small "patch" reef)

Structural Traps

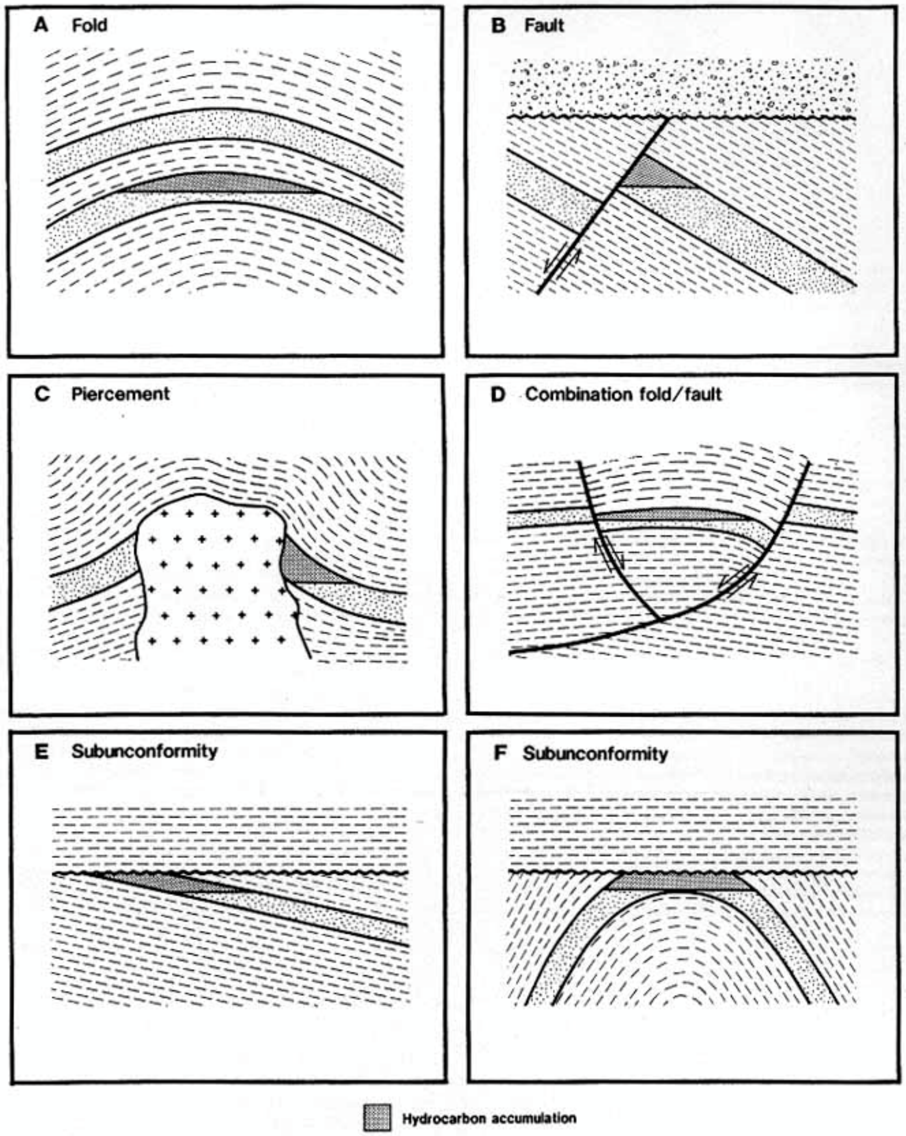
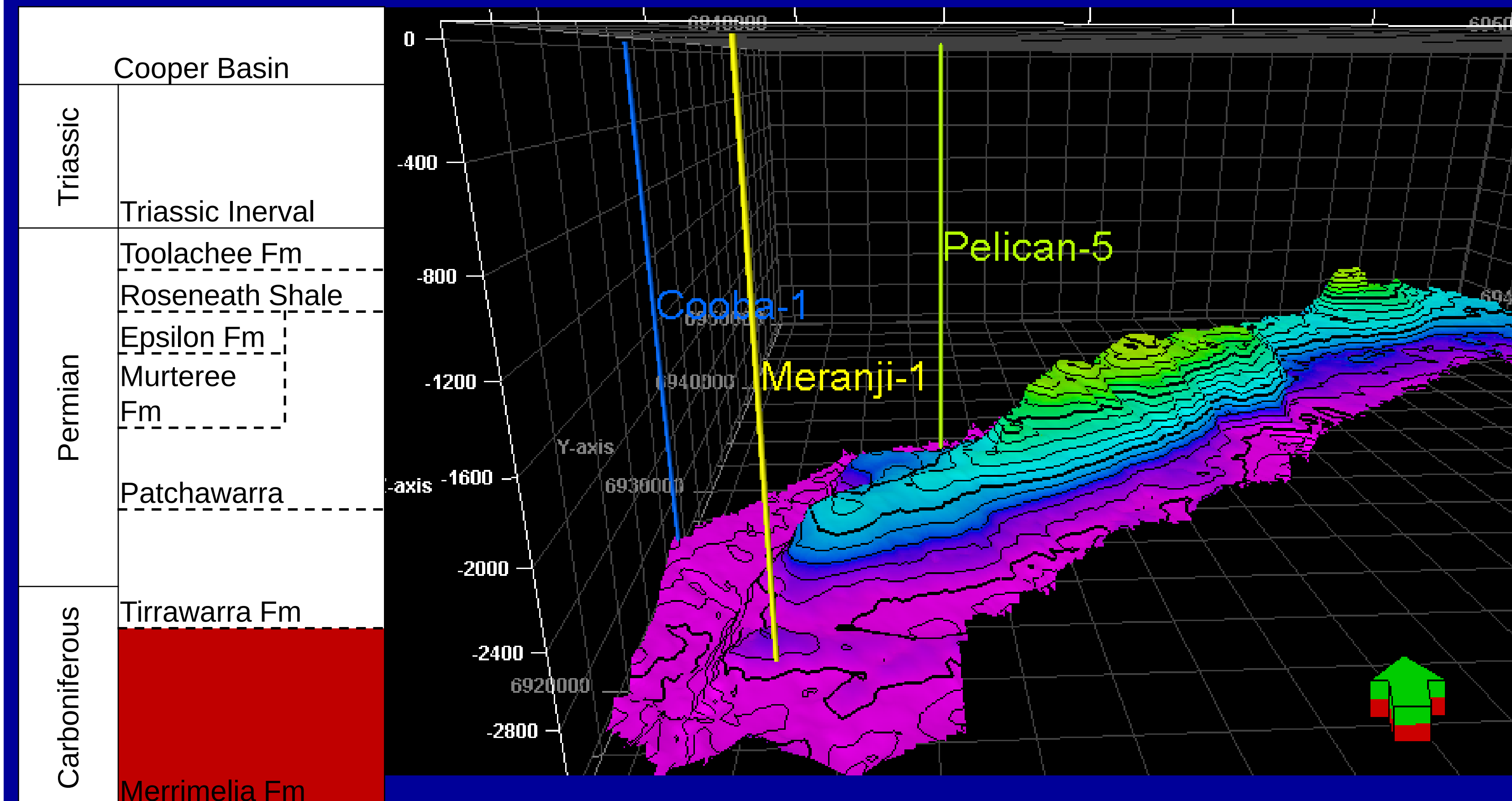


Figure 13.3. Major categories of structural traps: (A) fold, (B) fault, (C) piercement, (D) combination fold–fault, (E) and (F) subunconformities. The situation in (E) is commonly excluded from the structural category.

3D Structural Closure, Cooper Basin (Australia)



Merrimelia Fm:

- Starts the Cooper Basin
- Waxing and waning of glacial sediments

Trap Terminology

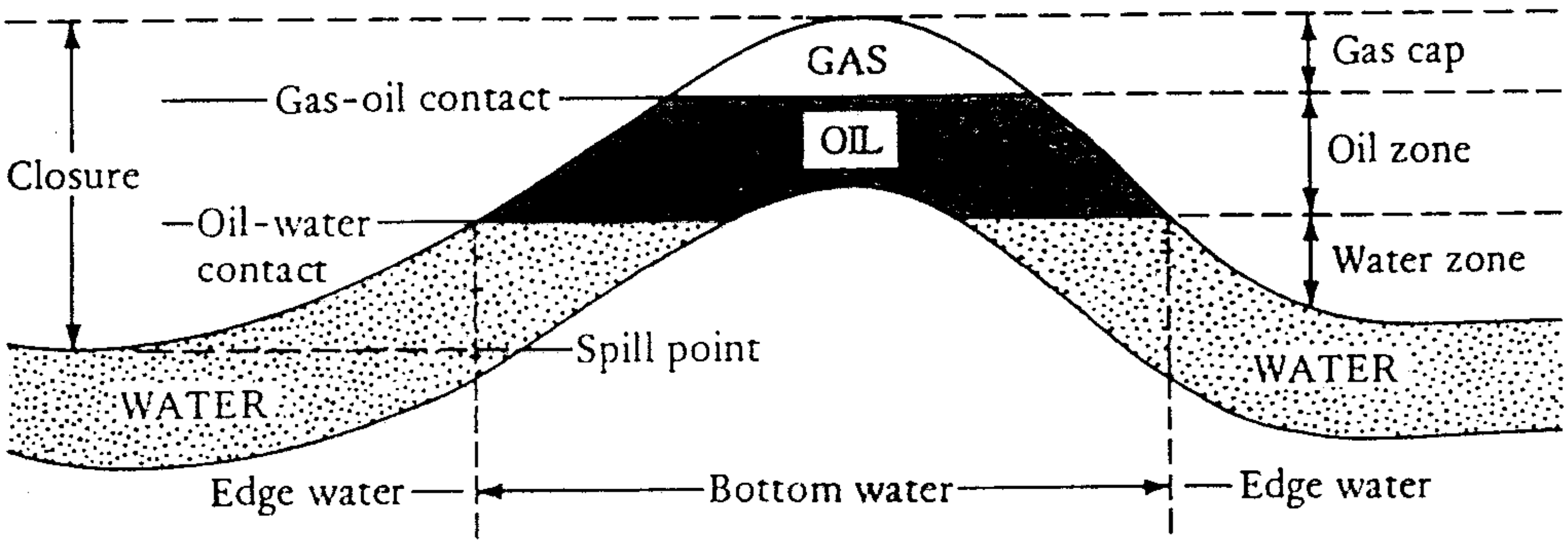


FIGURE 7.1 Cross-section through a simple anticlinal trap.

Fault Traps

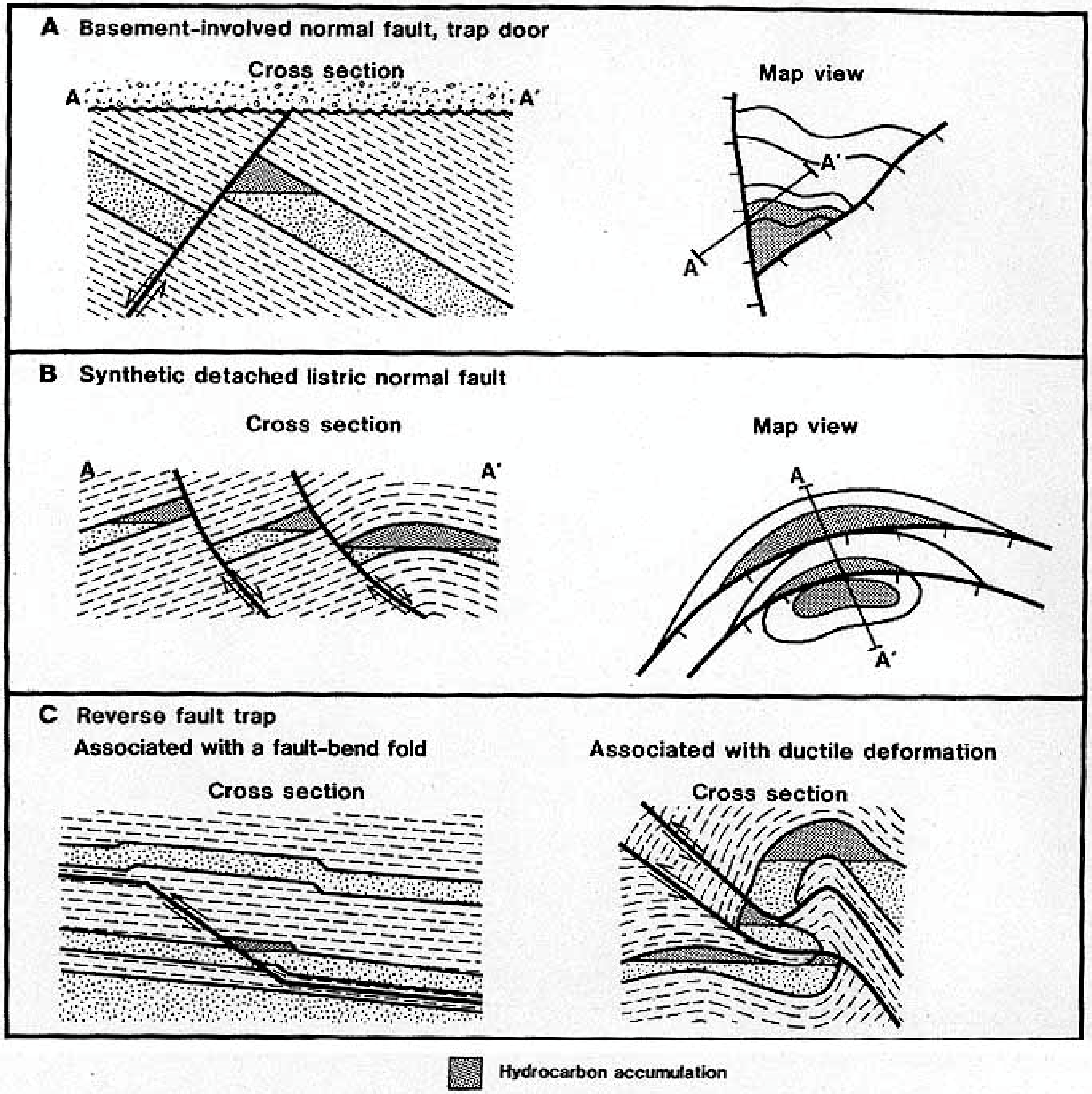


Figure 13.6. Types of traps in which faulting dominates the reservoir–seal interval. (A) Basement-involved normal fault trap and trap door. (B) Synthetic detached listric normal fault traps. (C) Two types of reverse fault traps. (D) Strike-slip fault traps.

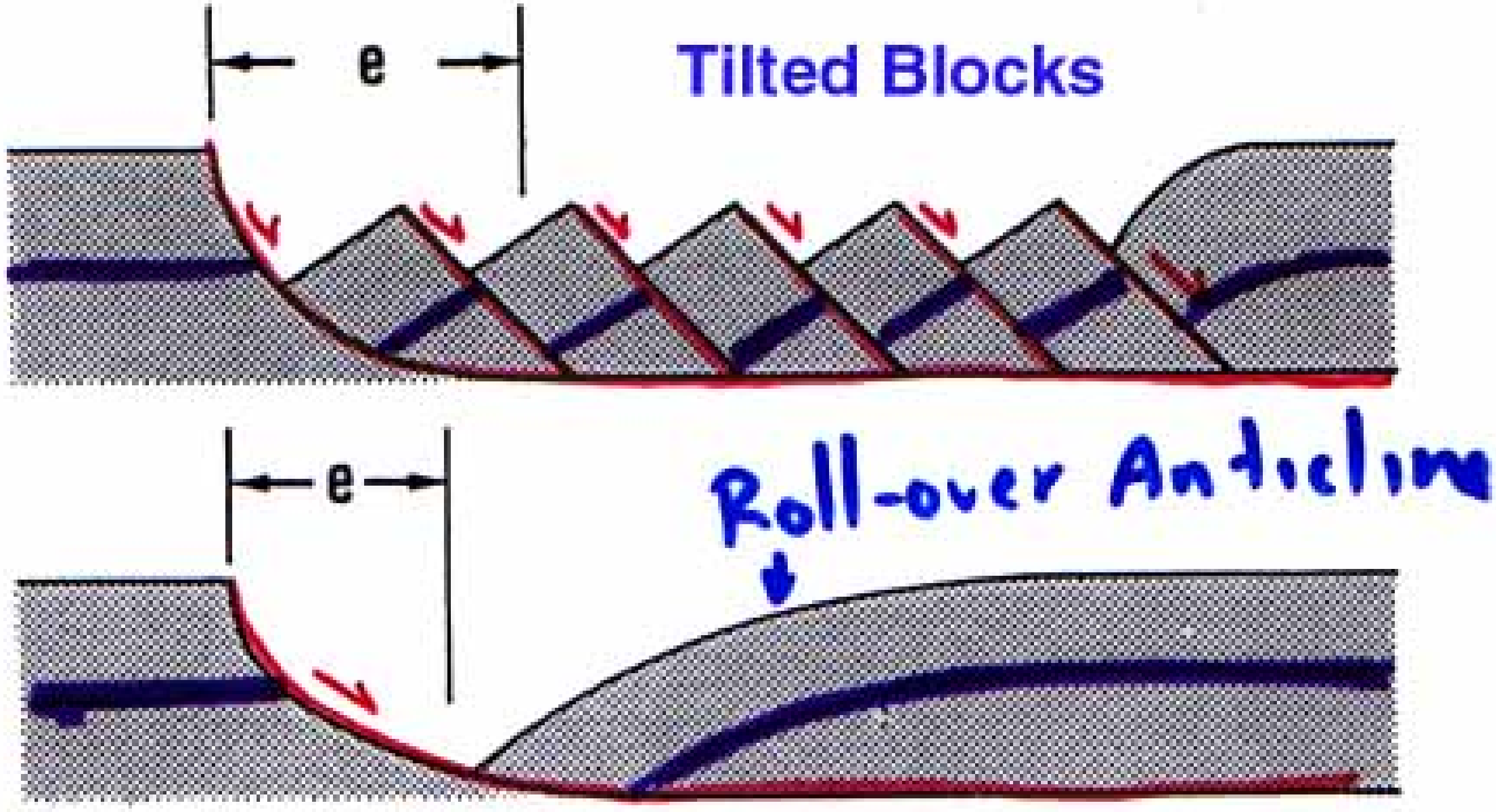
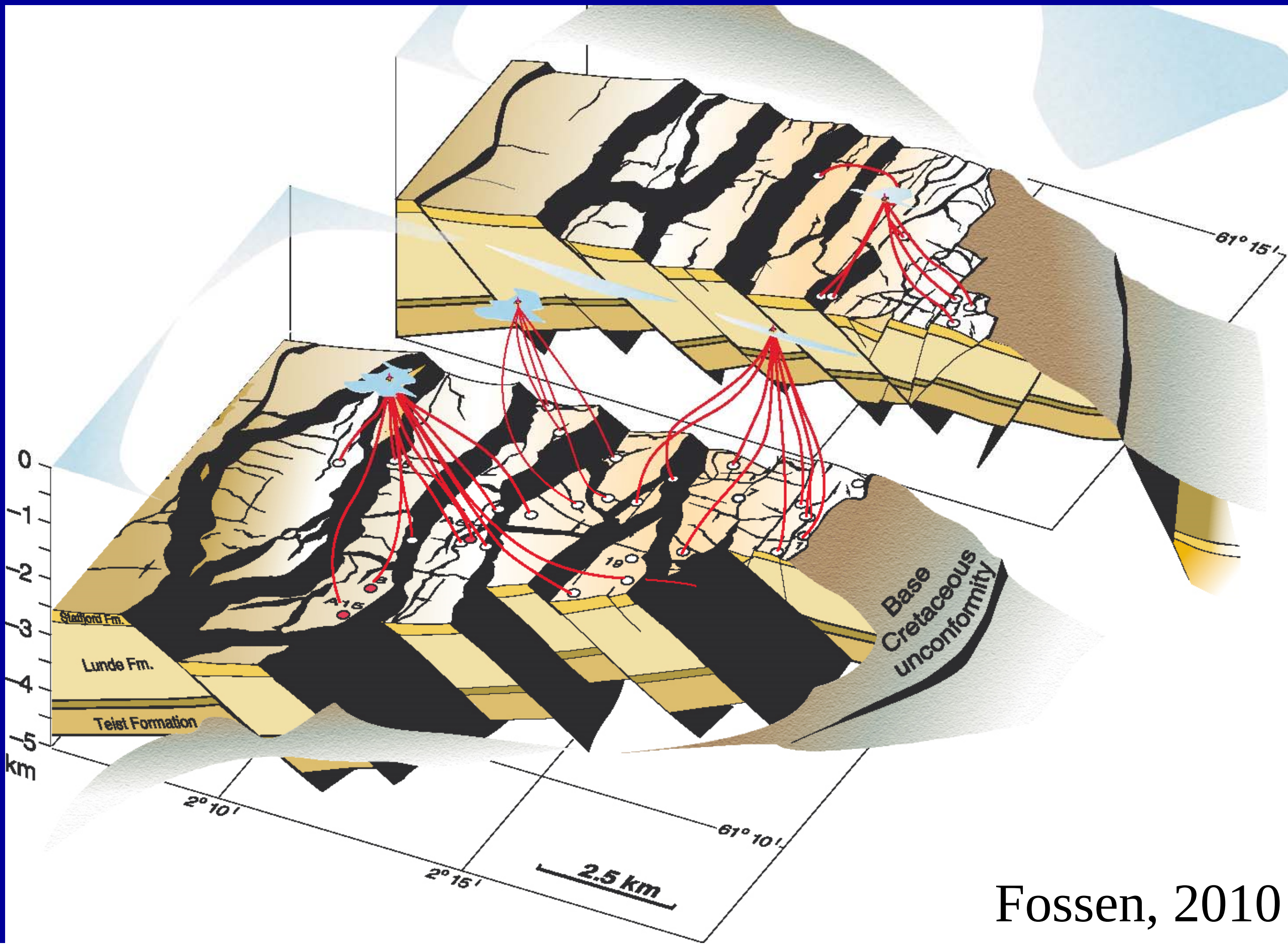


Figure 18 — Relationships between fault geometry and crustal displacement field, demonstrating that shallow-dipping faults, whether rotational or not, require substantial horizontal extension (e), and vice versa.

Gullfaks Field North Sea



Fossen, 2010

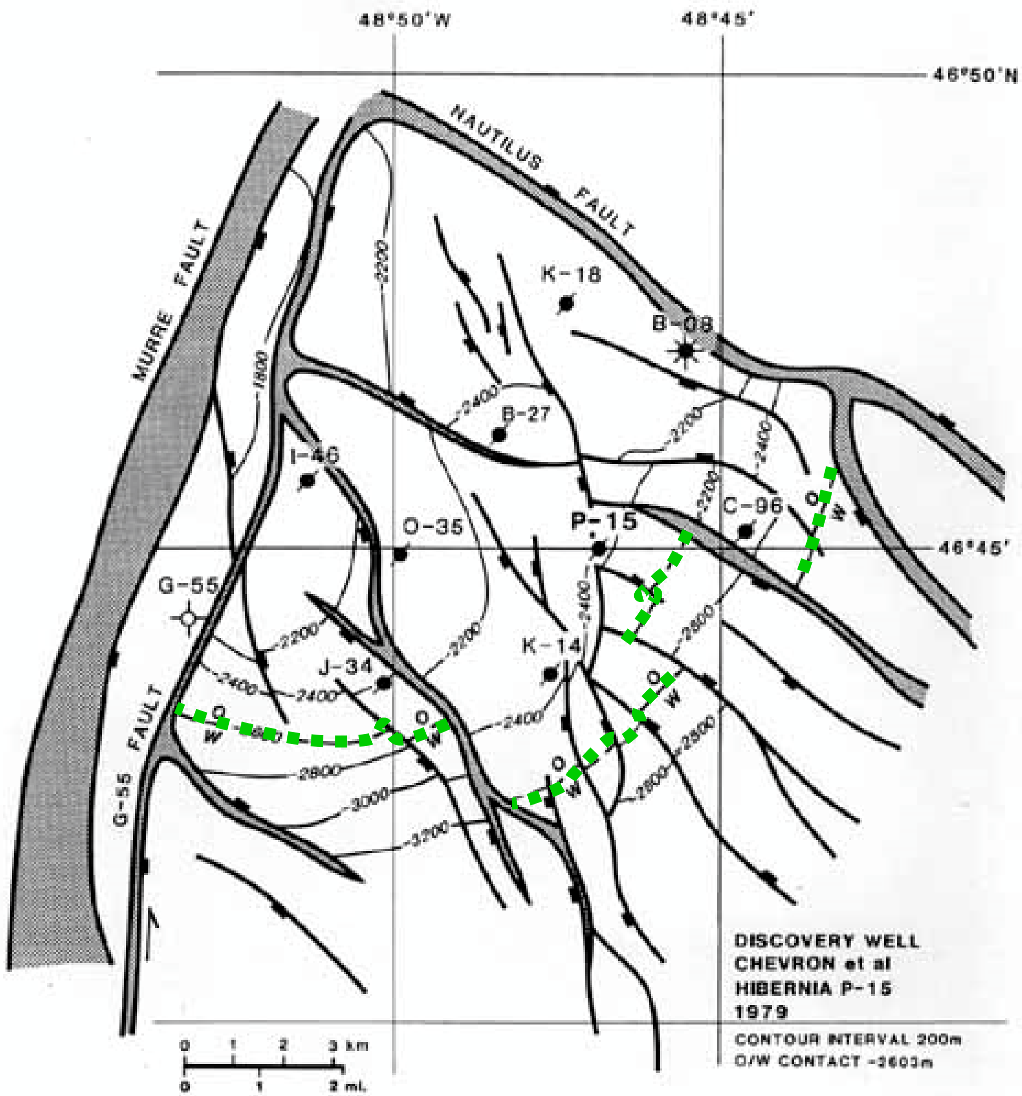


Figure 10. Depth-structure map at top of the Avalon reservoir. The structure is formed from the intersection of the Nautilus transfer fault with the listric normal Murre fault. The G-55 fault formed in post-rift time as a result of detachment and transport of Mesozoic cover down the axis of the basin, parallel to older basin-boundary faults.

Map of the Murre Field

Newfoundland

Compressional Traps

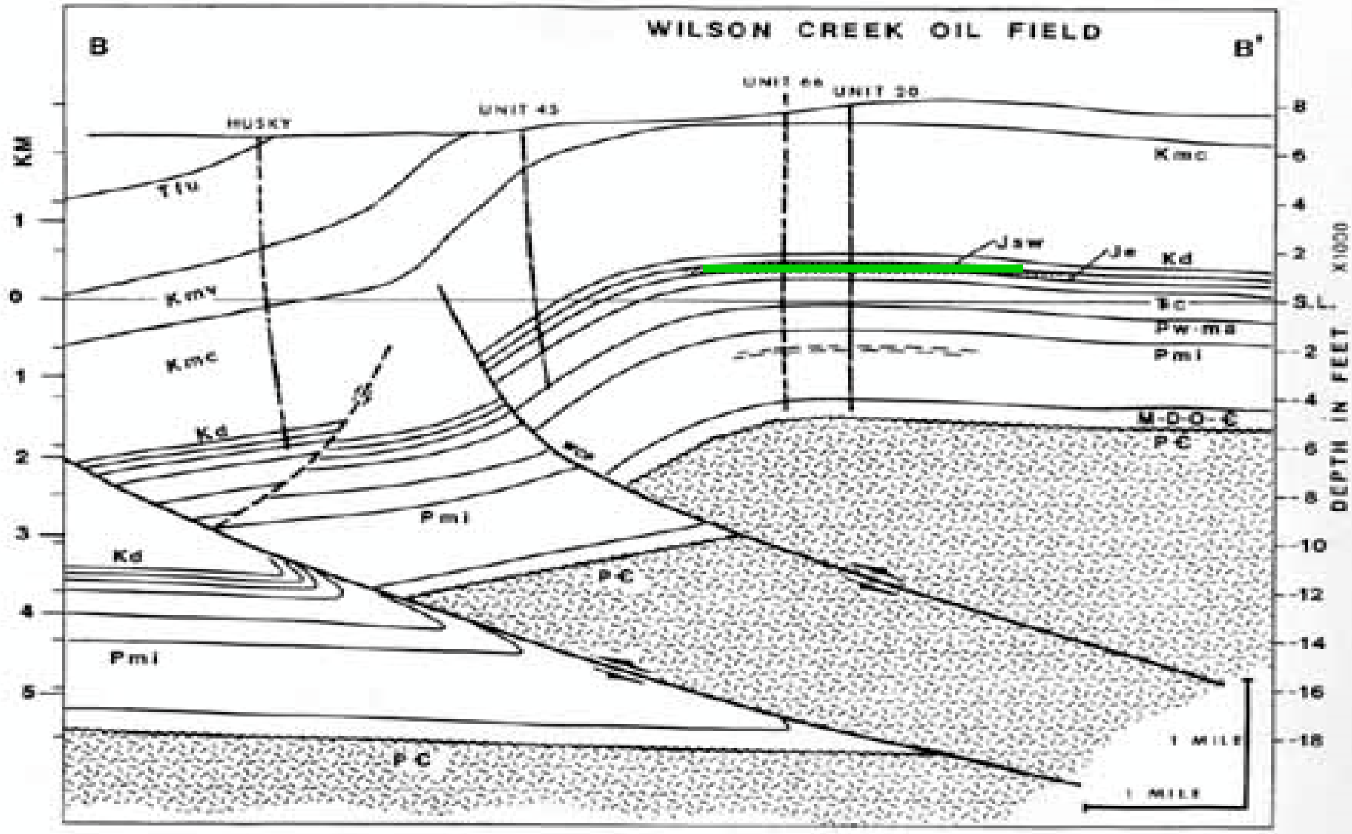
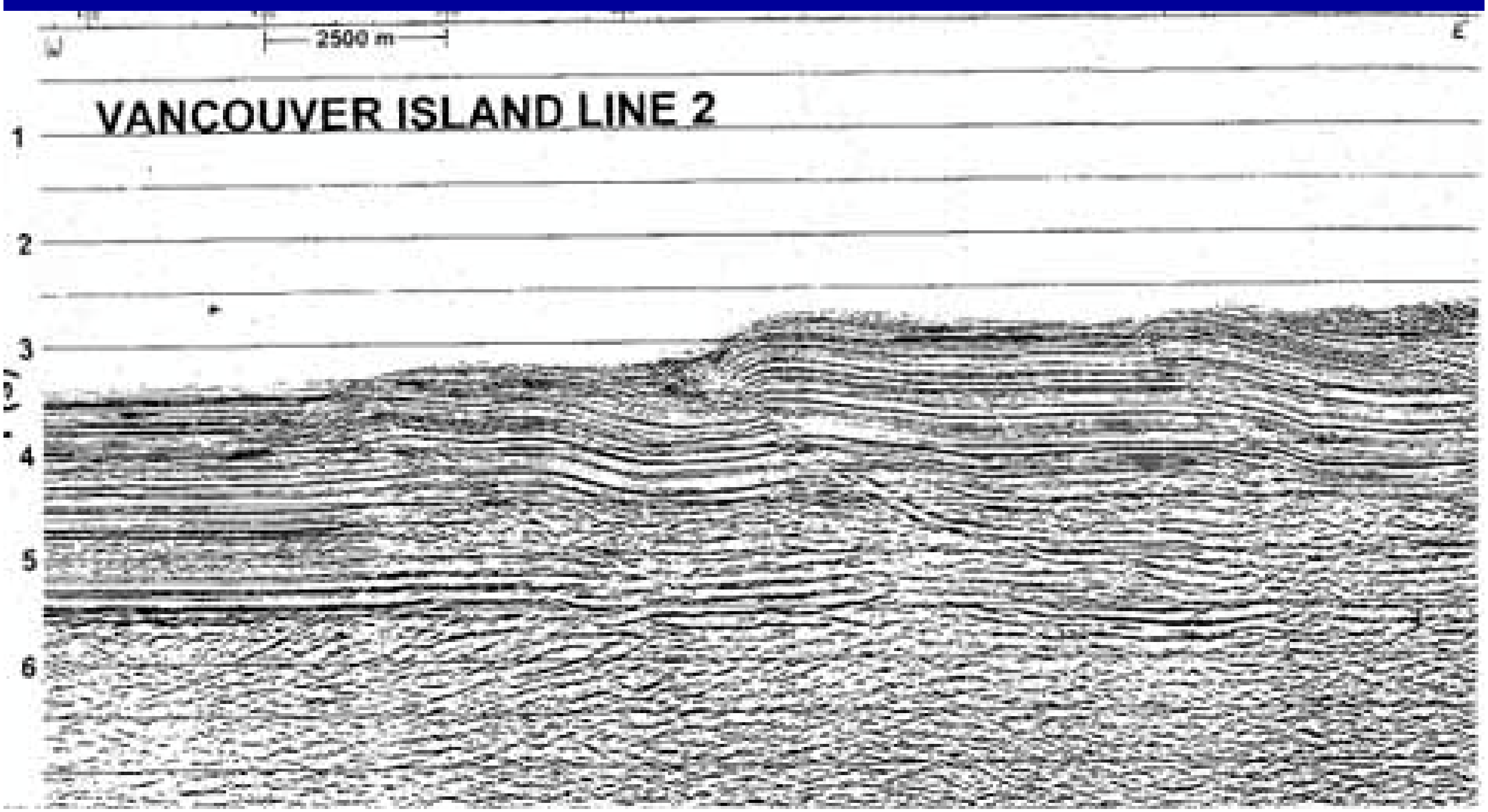


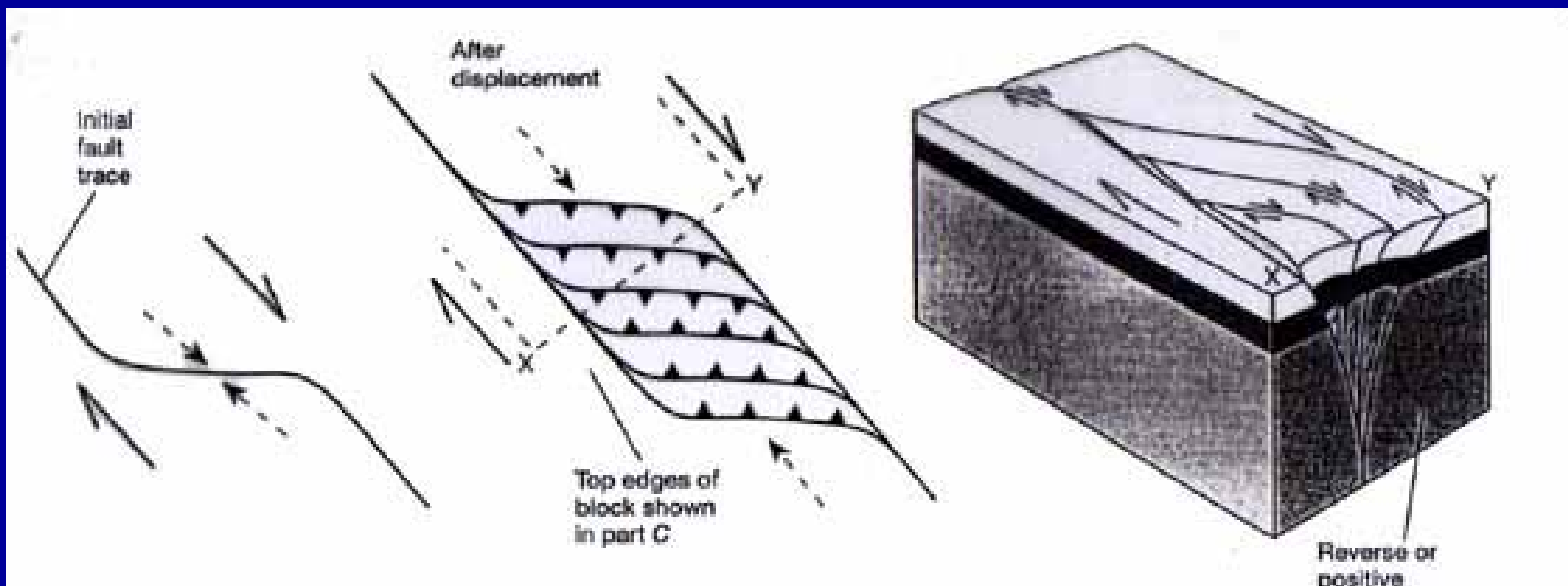
Figure 10. True-scale structural cross section B-B', Wilson Creek field (after Stone, 1986a). See Figure 11 for location. Cross-hatched area and dashed lines indicate hydrocarbon production. Formation symbols are: P€, Precambrian; M-D-O-€, Mississippian-Devonian-Ordovician-Cambrian; Pmi, Pennsylvanian Minturn; Pw-ma, Pennsylvanian-Permian Weber-Maroon; Trc, Triassic Chinle; Je, Jurassic Entrada; Jsw, Jurassic Salt Wash; Kd, Cretaceous Dakota; Kmc, Cretaceous Mancos; Kmv, Cretaceous Mesaverde; Tfu, Tertiary Fort Union. WCF, Wilson Creek fault.



2500 m
W
E
VANCOUVER ISLAND LINE 2
1
2
3
4
5
6

Traps in Strike-Slip settings

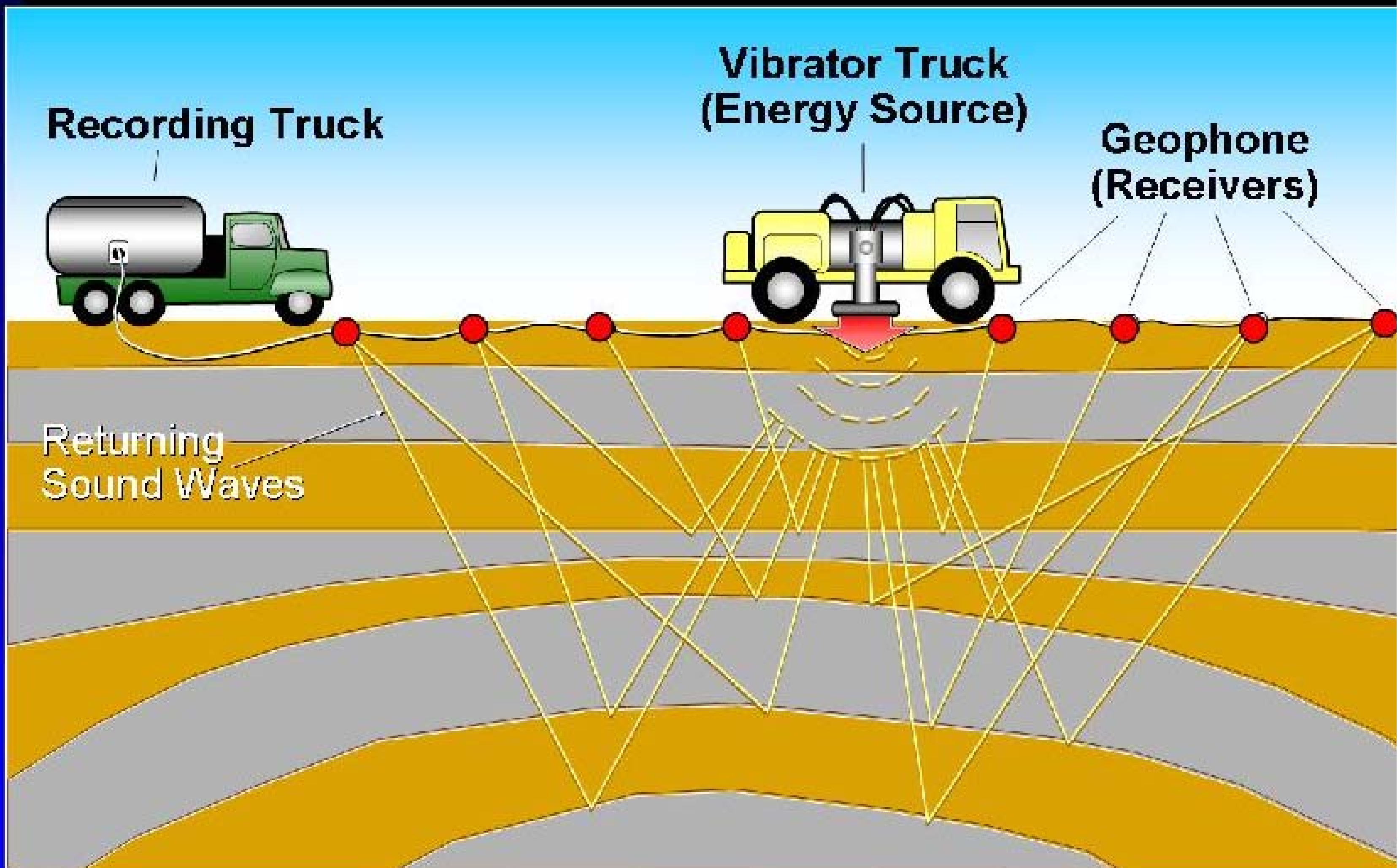
Positive Flower Structures



How to see in the subsurface?

- Drilling
- Structural Interpretation
- Seismic Reflection Imaging
  - Send sound into the rock, and collect the echoes

Seismic Imaging of Anticline



American Petroleum Institute, 19

MA

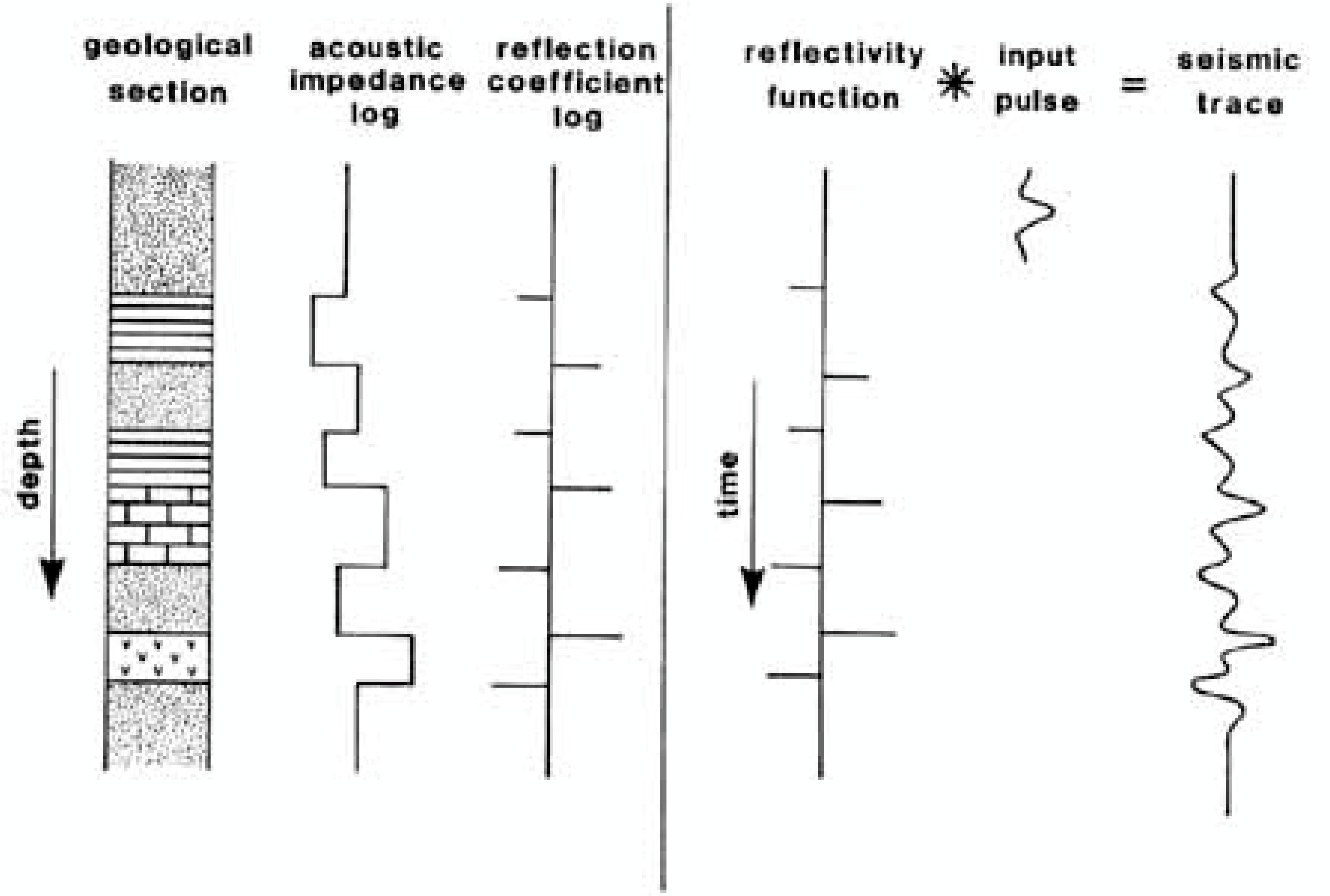
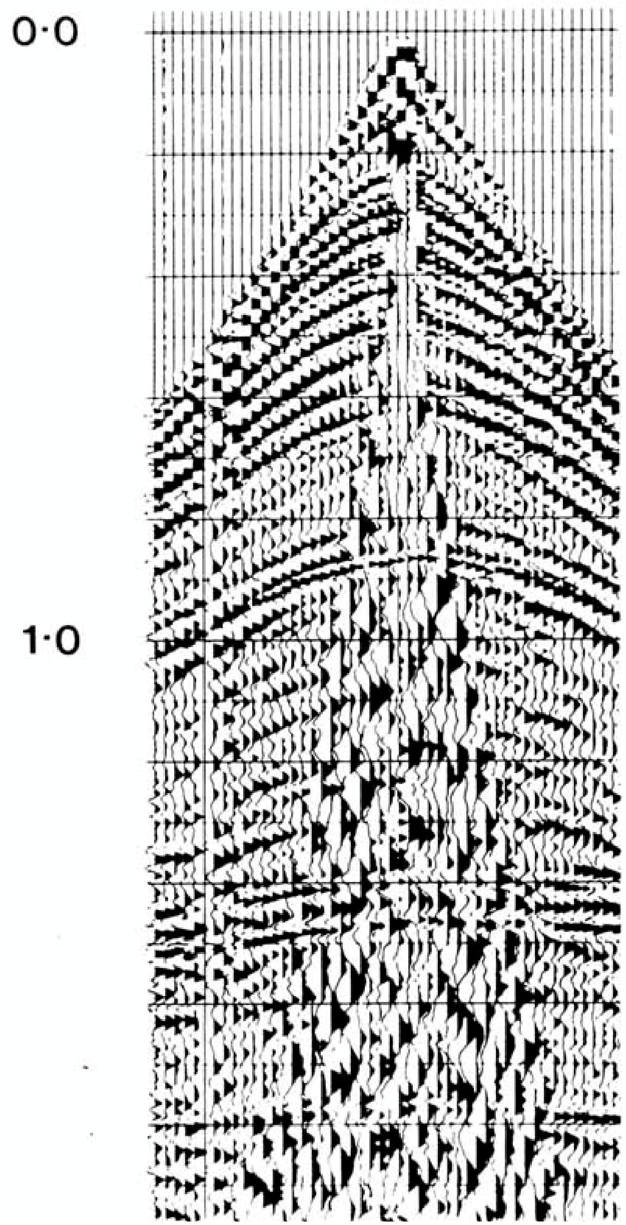
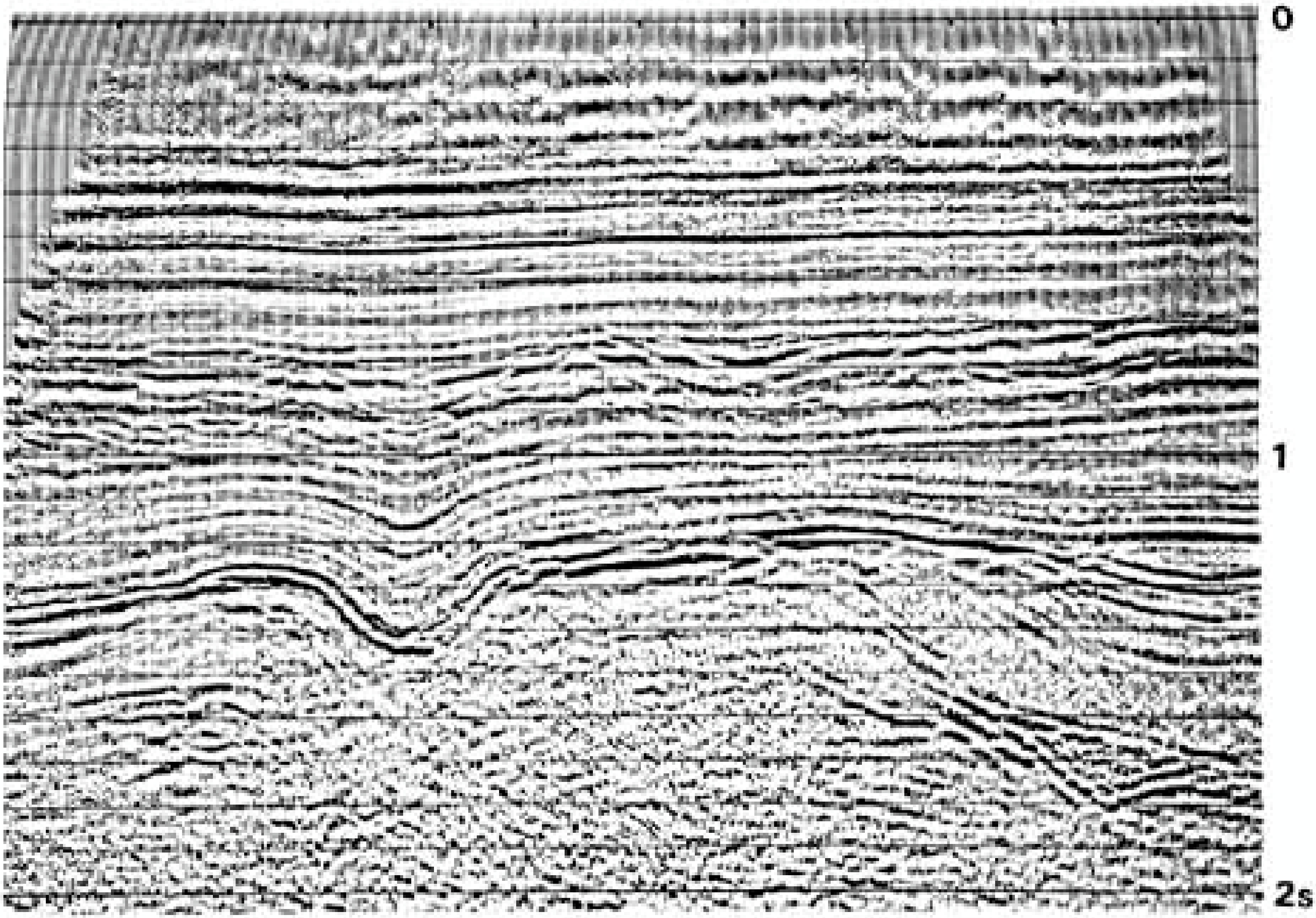


Fig. 4.7. The reflection seismogram viewed as the convolved output of a reflectivity function with an input pulse.

Seismic shot gather-

Every vertical squiggle is from one geophone

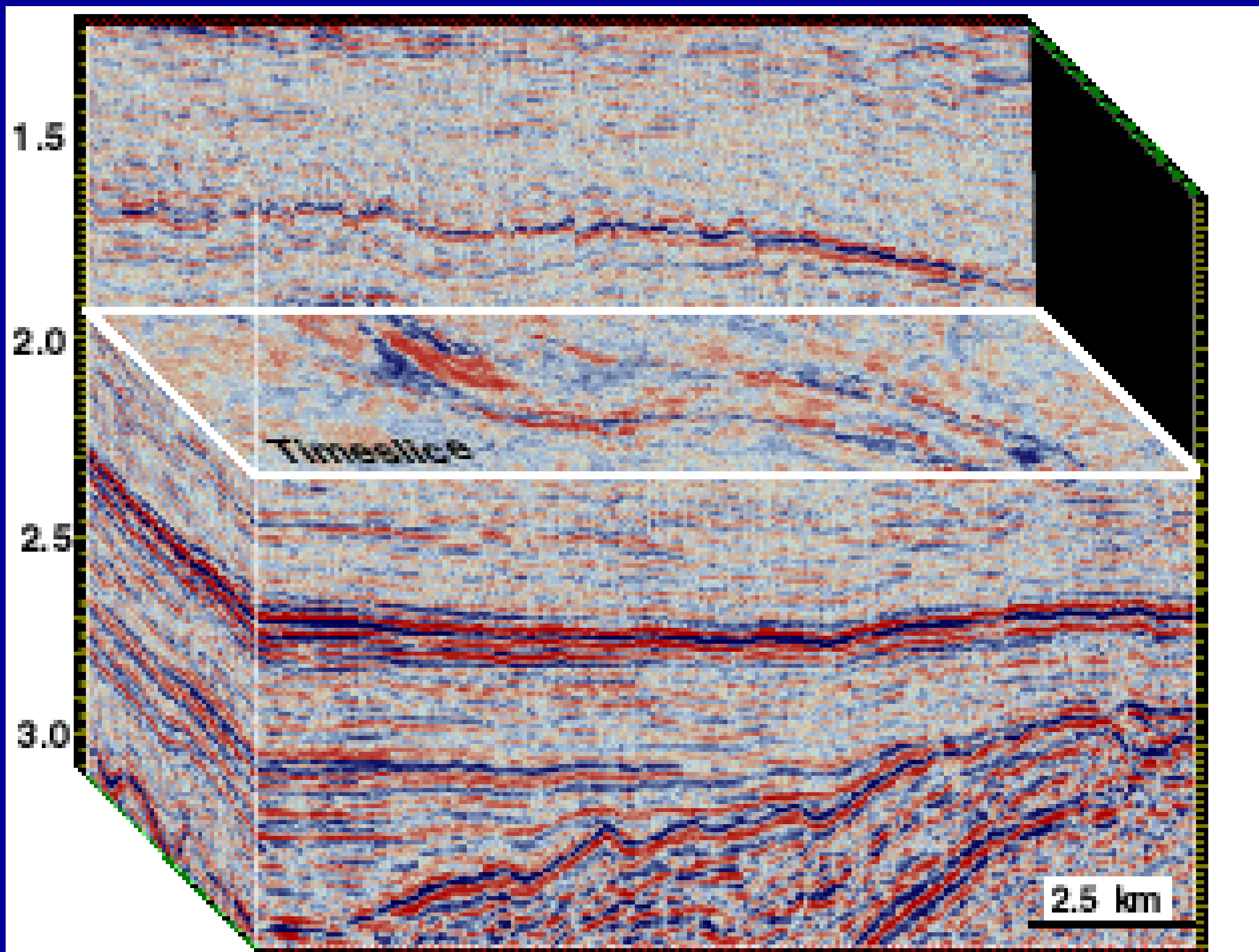




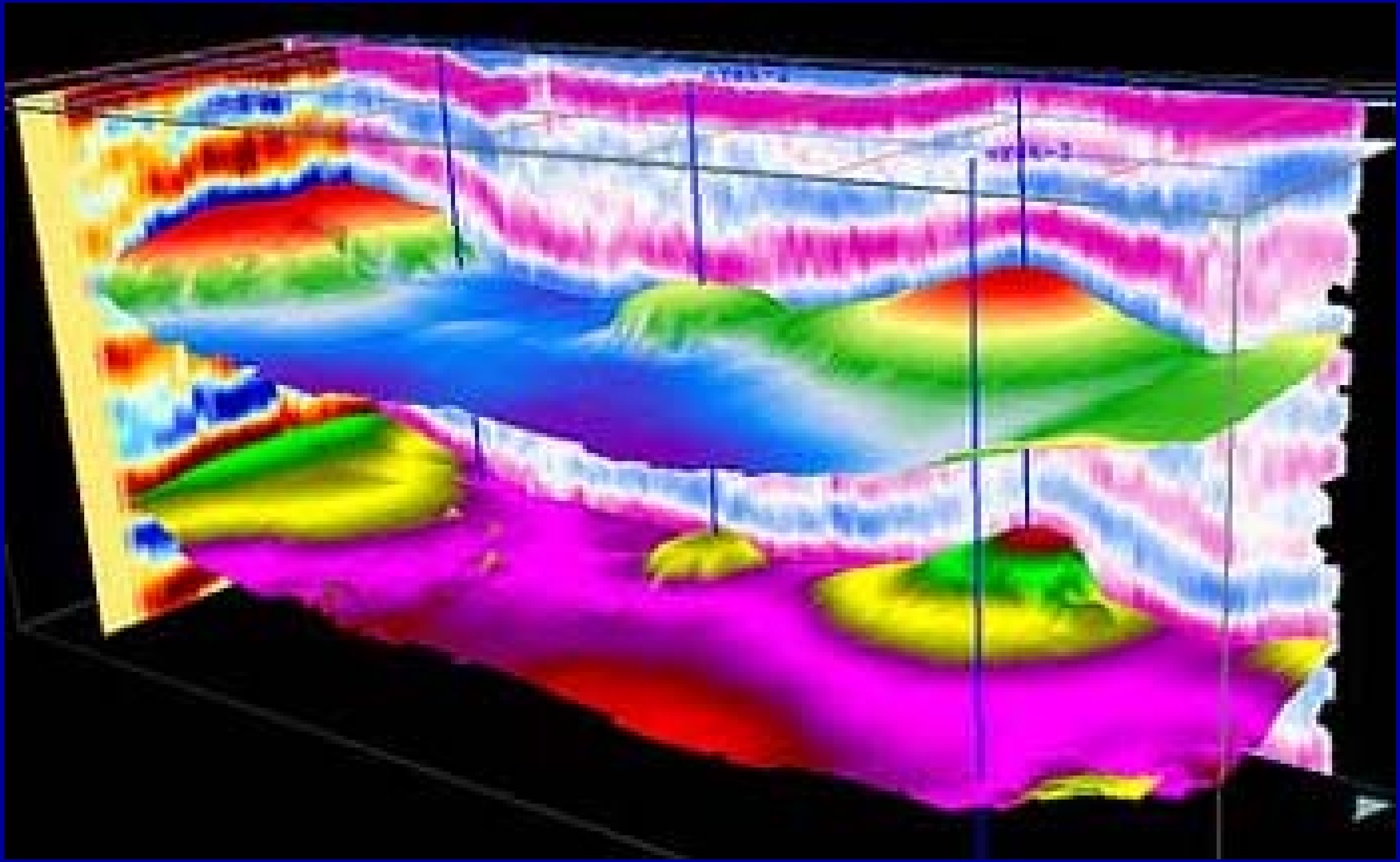
(b)

Fig. 4.26. (a) A non-migrated seismic section. (b) The same seismic section after wave equation migration. (Courtesy Prakla-Seismos GMBH.)

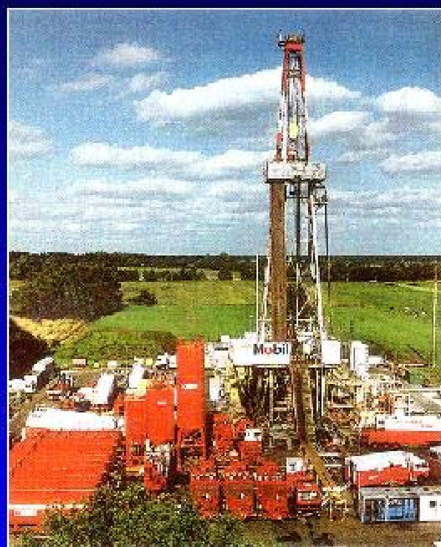
3D Seismic Image

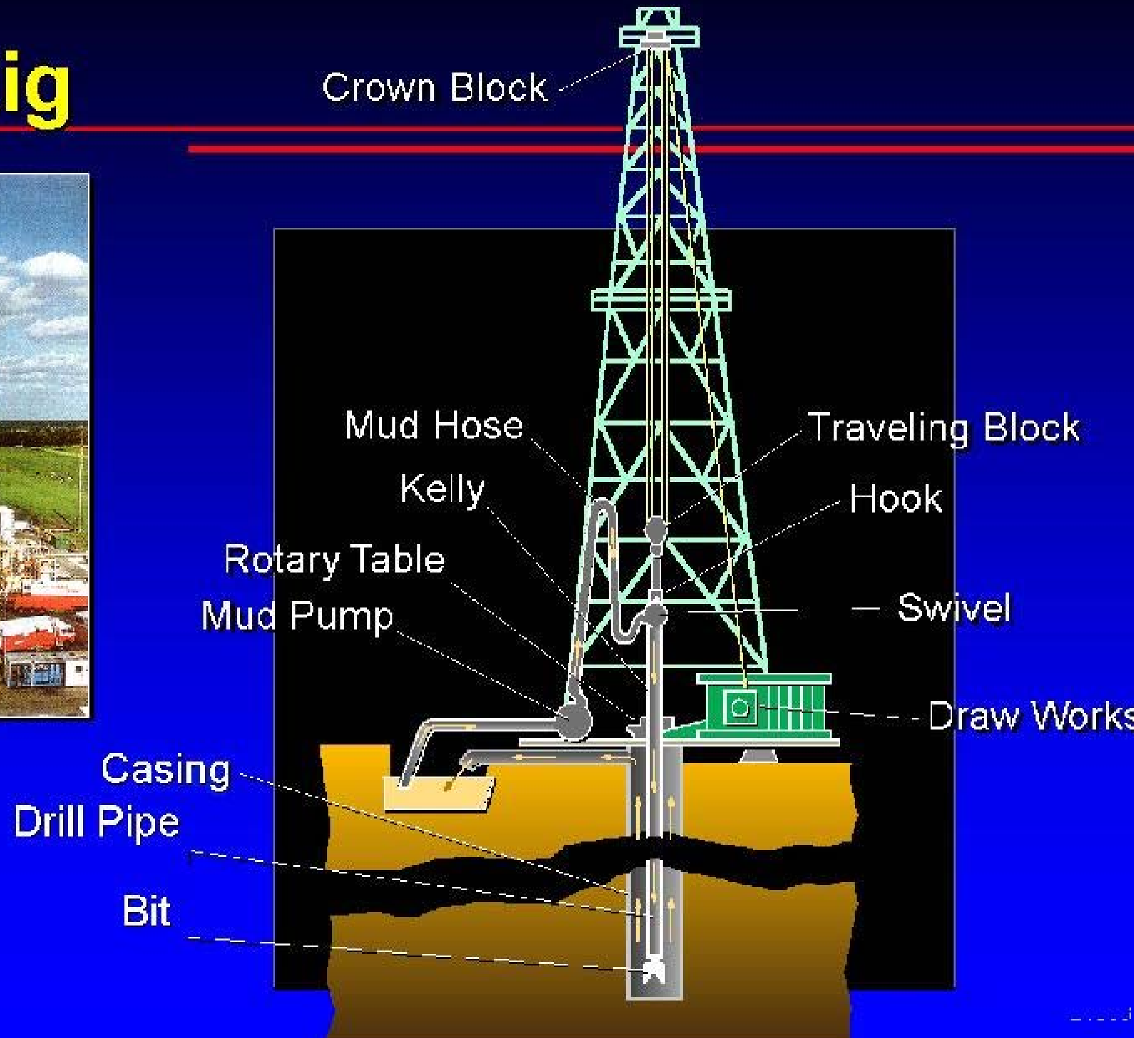


3D Geological Model

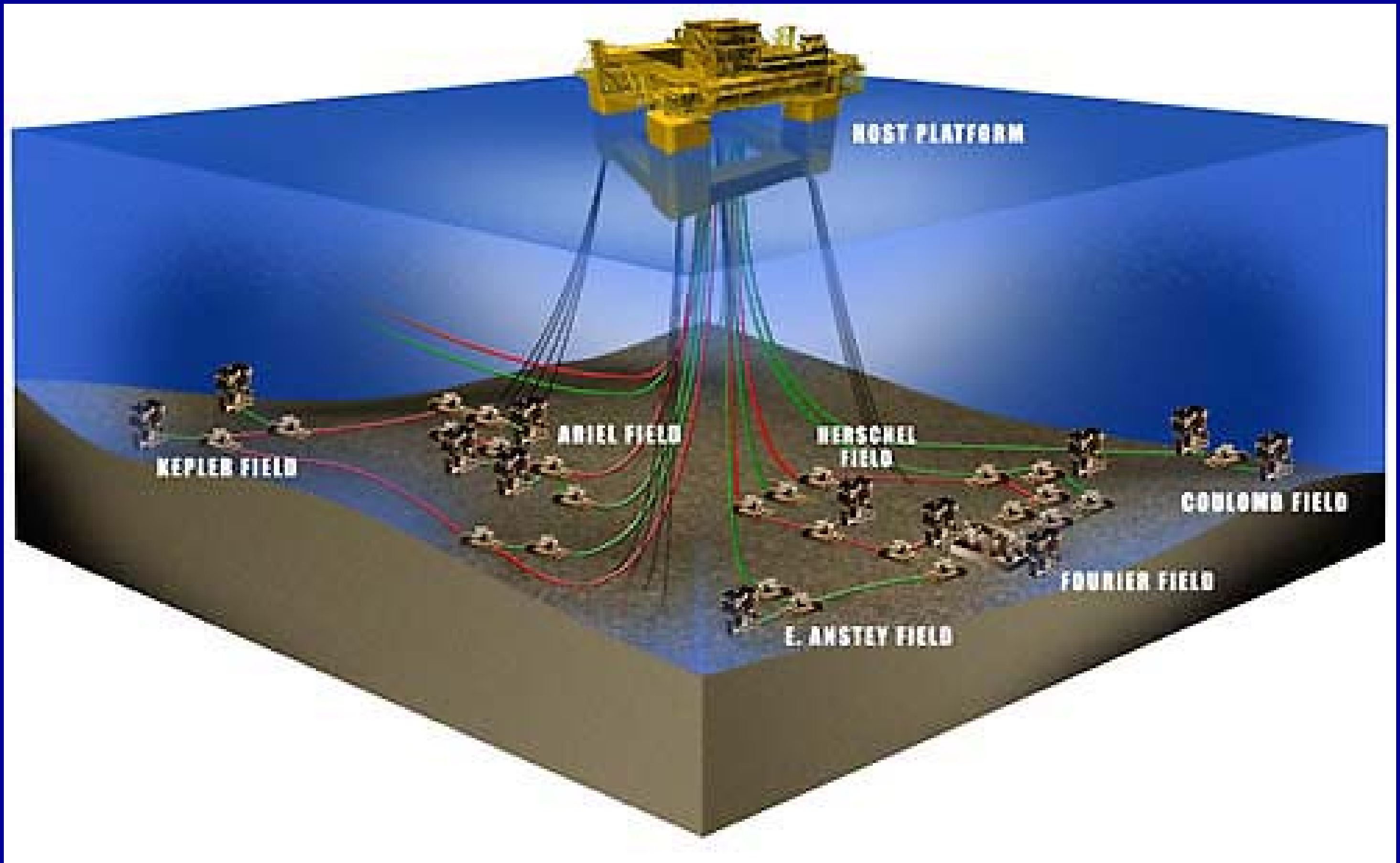


Drilling Rig





Offshore Platform



Maui Field, New Zealand

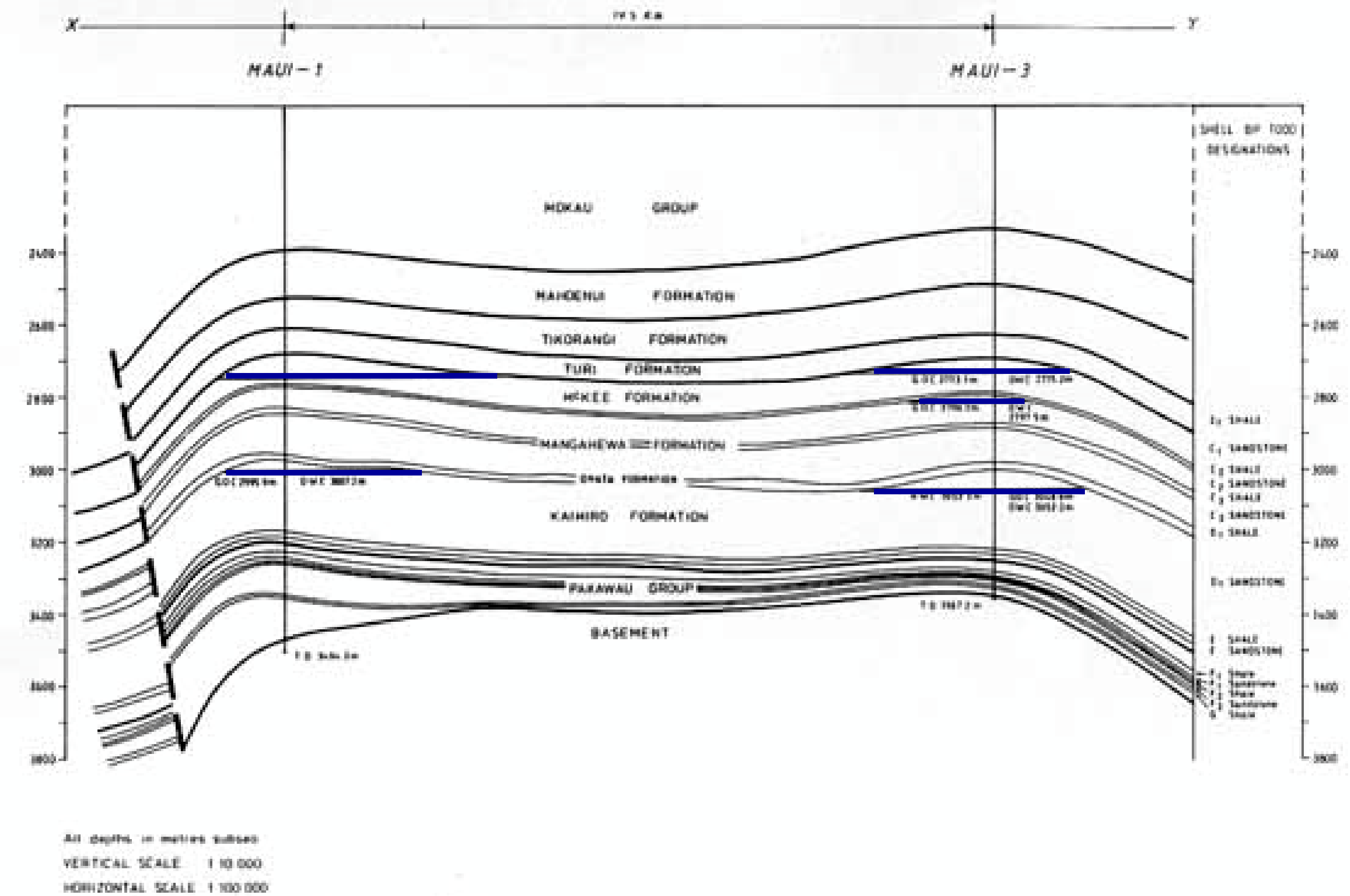
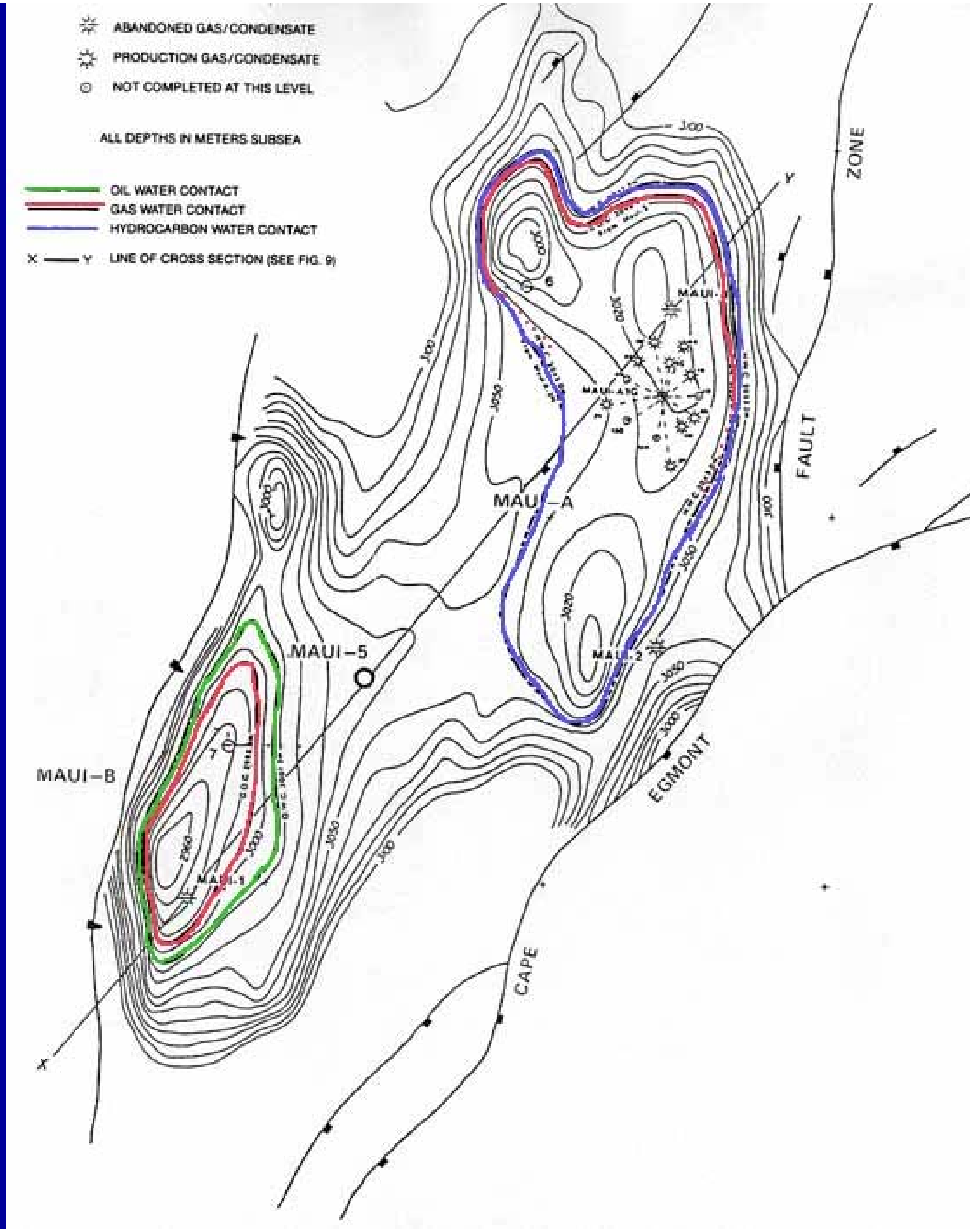


Figure 9. Geological cross-section between Maui-1 and Maui-3 (after Haskell, 1986). See Figure 4 for location and Figure 10 for seismic profile.


ABANDONED GAS/CONDENSATE
PRODUCTION GAS/CONDENSATE
NOT COMPLETED AT THIS LEVEL
ALL DEPTHS IN METERS SUBSEA
OIL WATER CONTACT
GAS WATER CONTACT
HYDROCARBON WATER CONTACT
X — Y LINE OF CROSS SECTION (SEE FIG. 9)
MAUI-A
MAUI-5
MAUI-B
MAUI-1
MAUI-2
MAUI-A3C
CAPE EGMONT FAULT ZONE
3000
3050
3100
2950

Horizontal Marcellus Wells in Northern PA

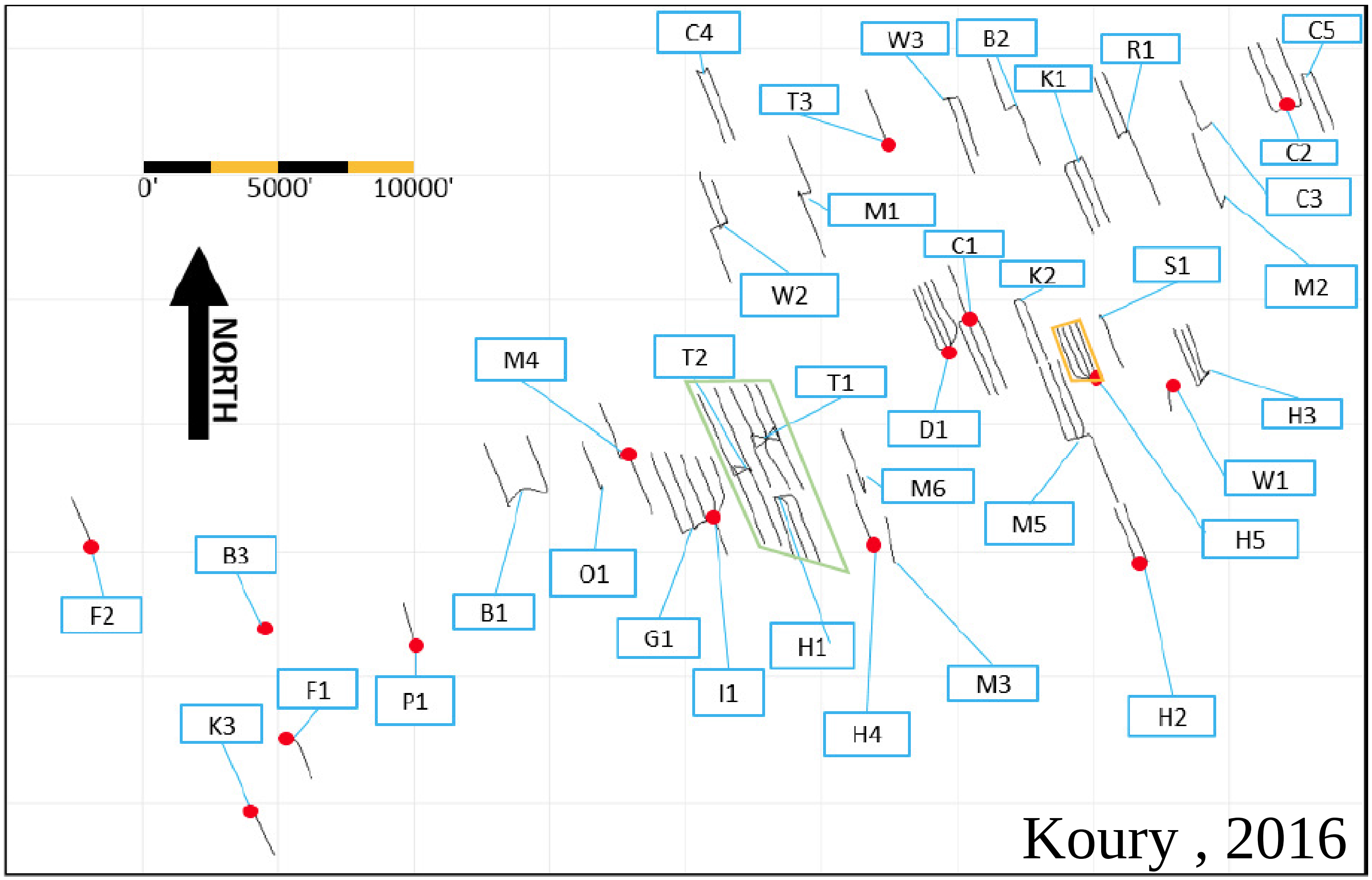


*Figure 6a: Locations of vertical gamma ray type logs (**RED**) and horizontal wellbores (Black)*

Well Log Measured While Drilling (MWD Log)

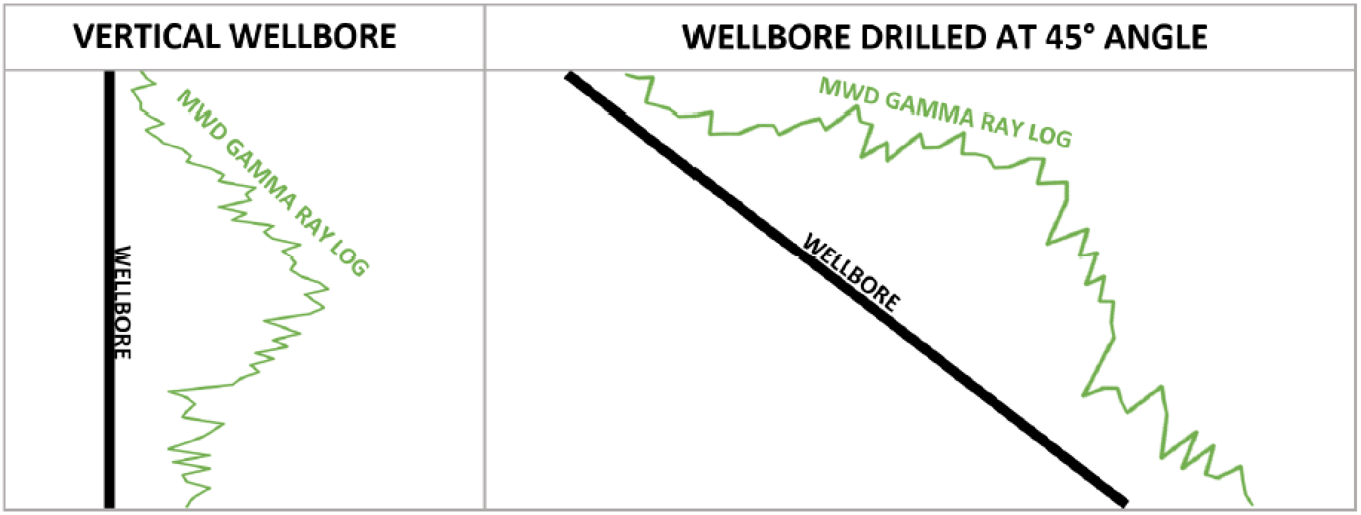
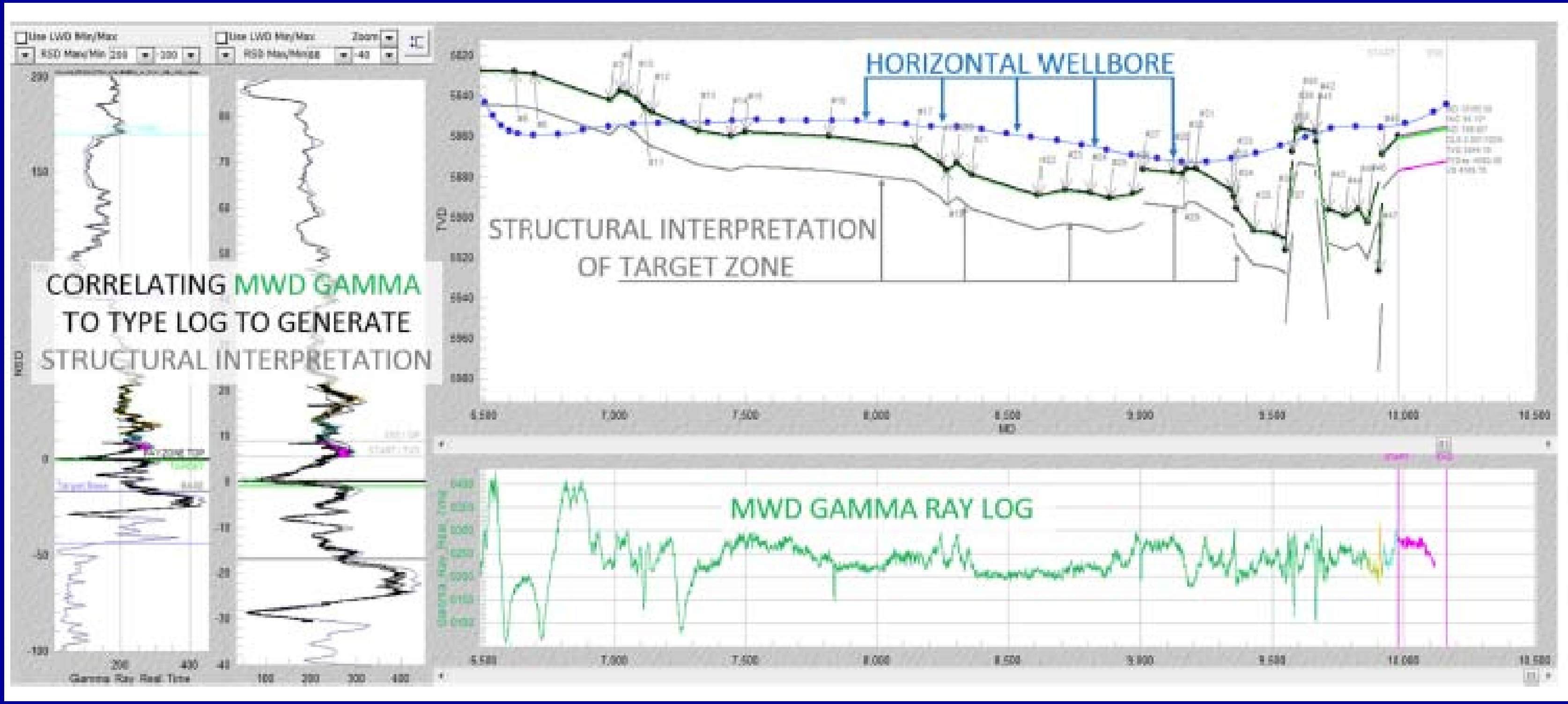


Figure 7: Illustration of how differing drilling inclinations will generate gamma signatures of similar signature, but differing length.

Geosteering A Well With Interpretation



What the wellbore sees as it drills the structure

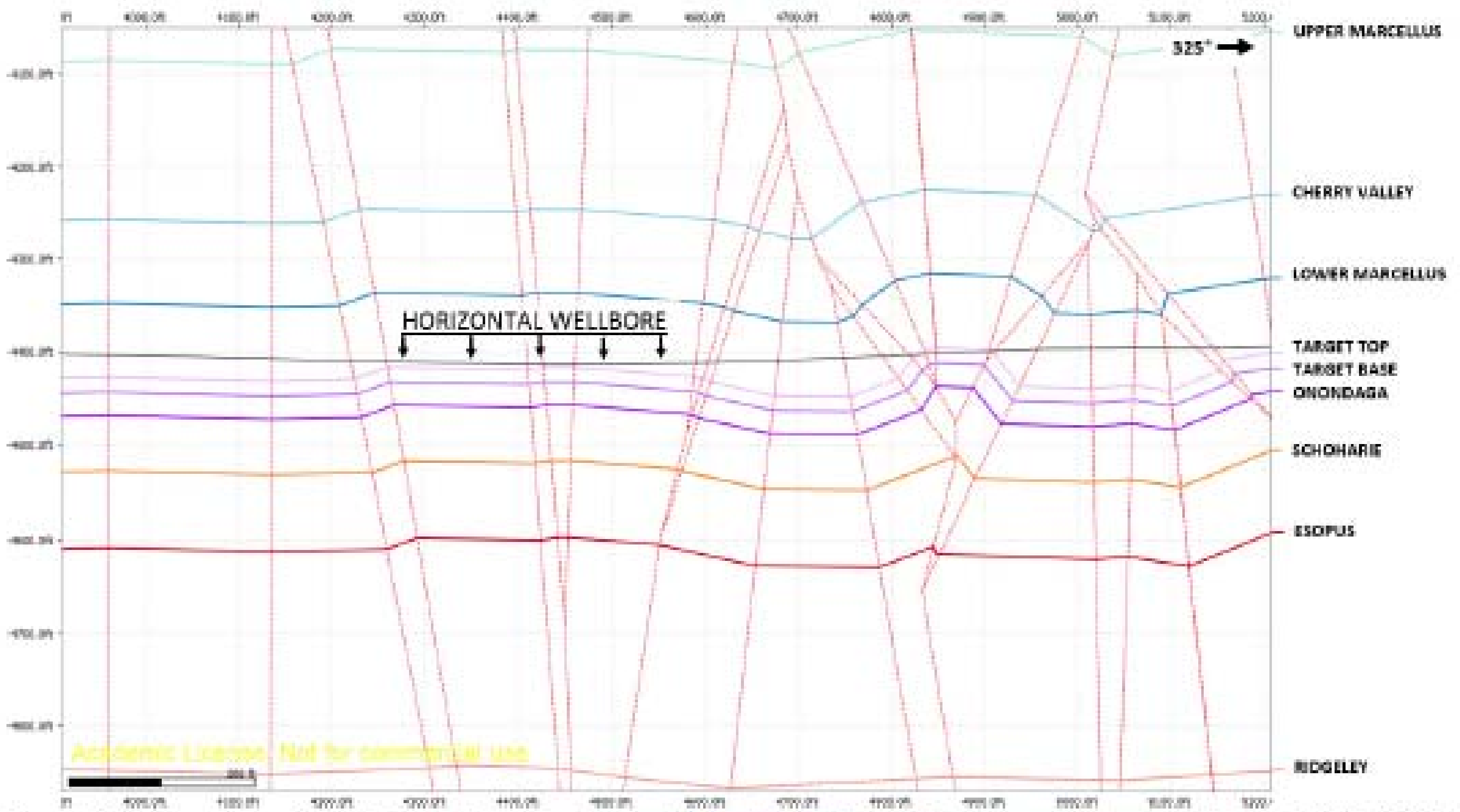


Figure 12: Cross section of the H5 1H horizontal well using Midland Valley's MOVE software. Image created using MOVE v.2015.1

Subsurface structure based on multiple adjacent horizontal wells

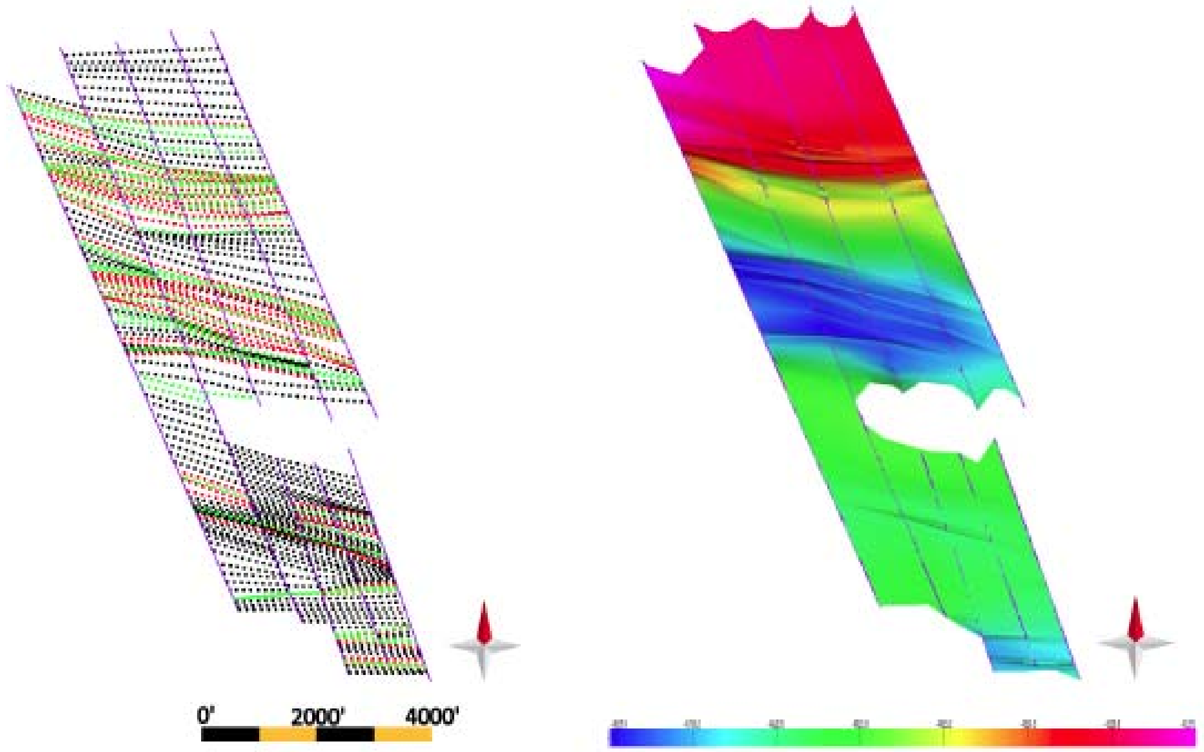
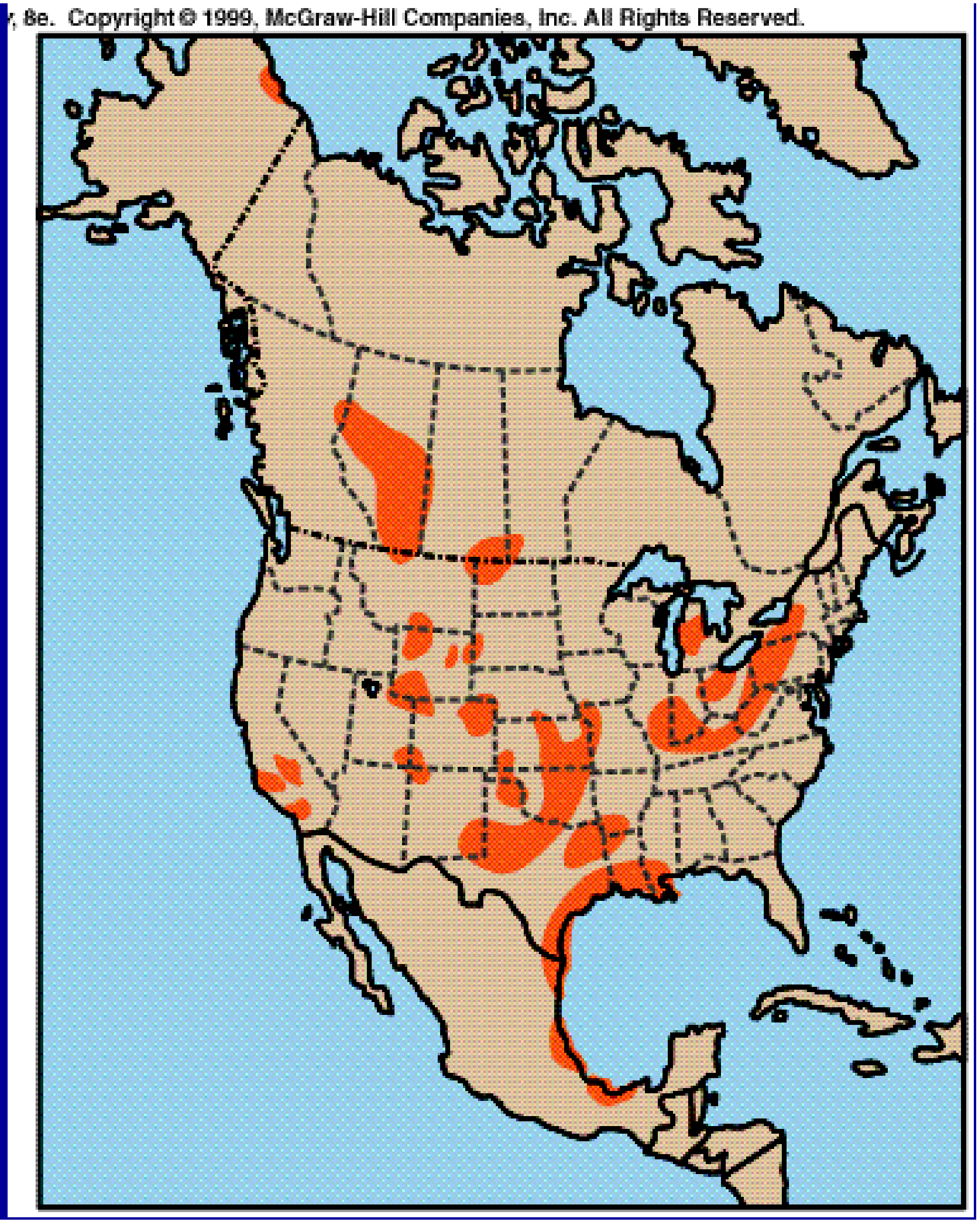


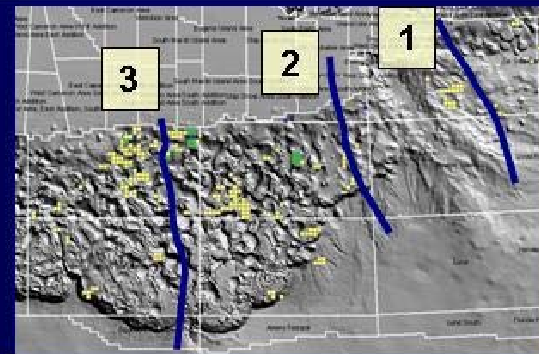
Figure 15: Delineation of folds across adjacent wellbores guided the generation of an Onondaga Formation surface map in MOVE. GREEN lines signify anticlinal hinges, RED lines signify synclinal hinges, and **BLACK** lines were placed to supplement and guide the mapping software.

Major Hydrocarbon Provinces in North America

Sedimentary Basins



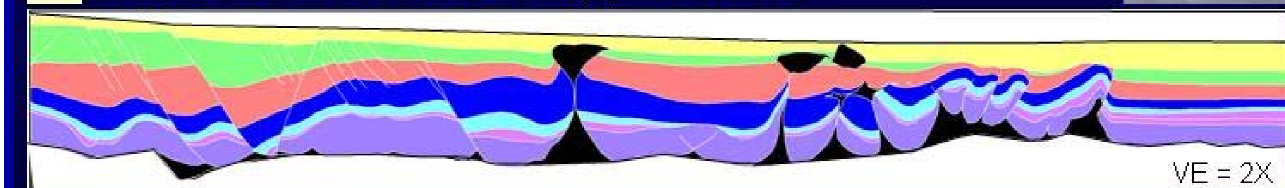
Gulf of Mexico: Regional cross sections



The primary basin section is variably discontinuous

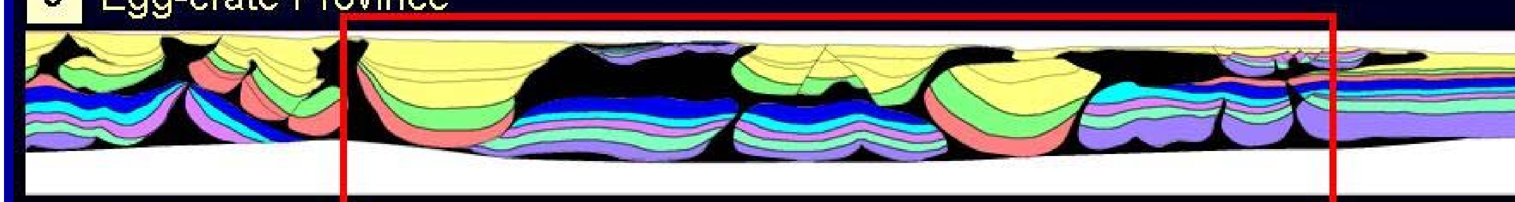
East: Primary basins are open or separated by salt ridges
West: Primary basins are separated by young mini-basins

1 Immature Salt Stock Canopy Province



2 Mature Salt Stock Canopy Province

3 Egg-crate Province



- Pleistocene
- Pliocene
- U. Miocene
- M.Miocene
- L.Miocene
- Oligocene
- Eocene-Paleocene
- (Paleocene)
- K-Jurassic

East
West

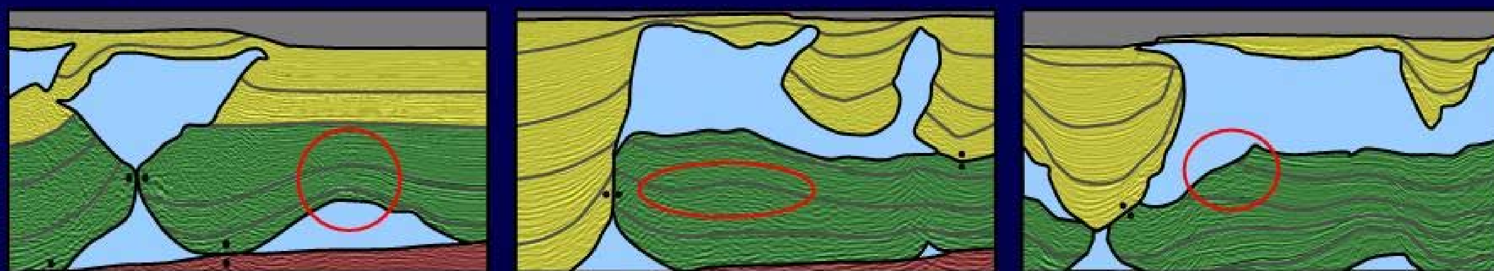
Primary Basin Boundaries in the Gulf of Mexico

Pilcher et al. 2009

Primary Basin Trap Styles

Primary Basin Centered Traps

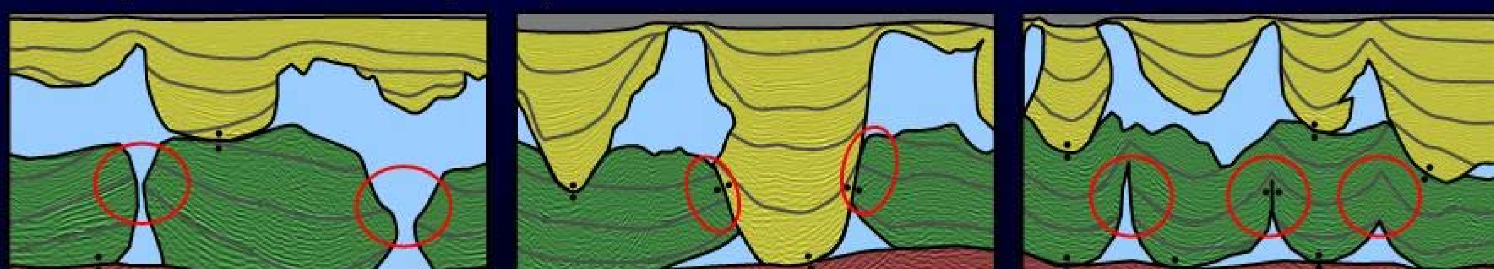
(1)



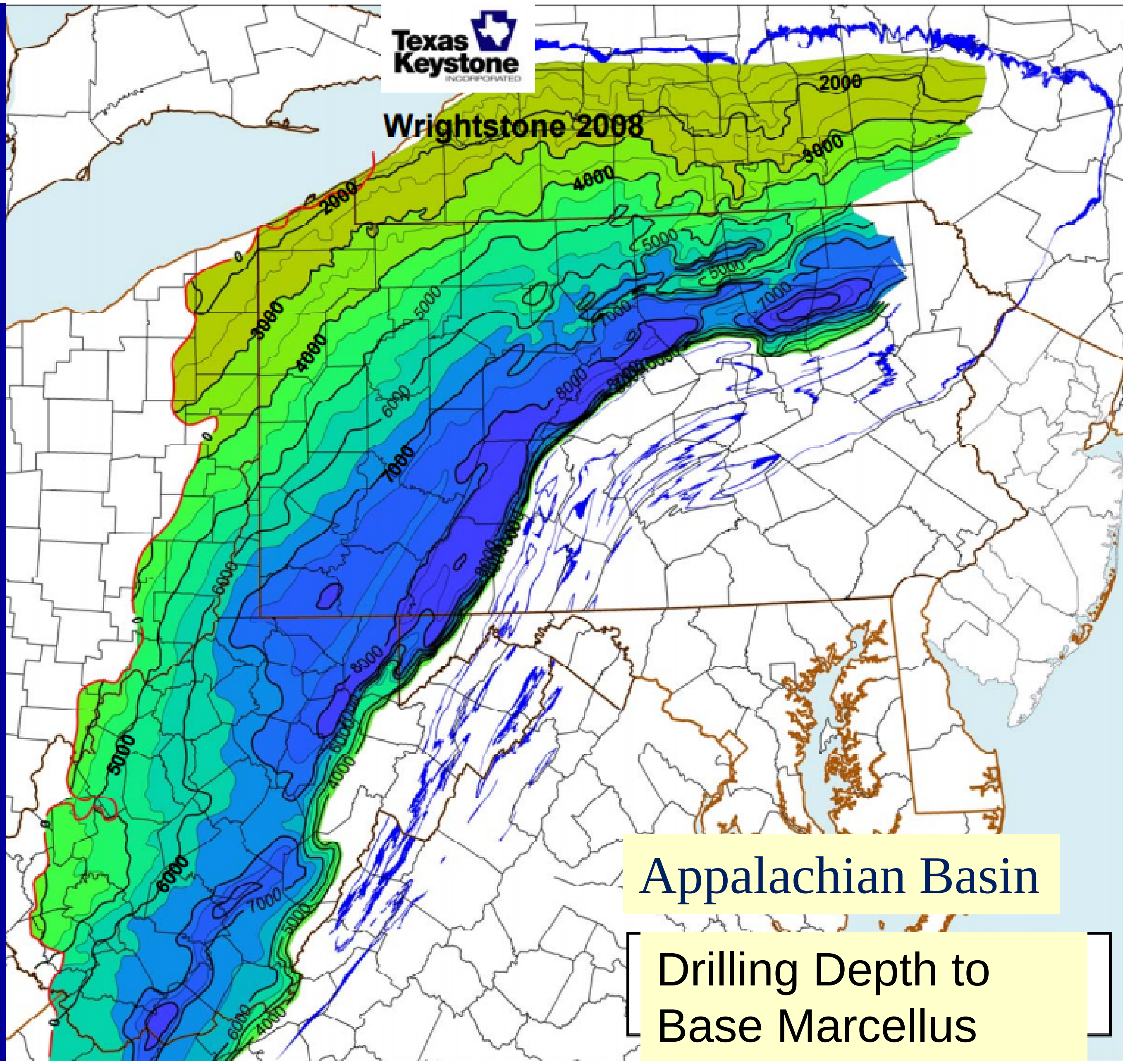
(a) Salt Cored Fold: 4-way closure | (b) Turtle Structure: 4-way closure | (c) Base Salt Truncation: 3-way closure

Primary Basin Boundary Traps

(2)



(d) Salt Feeder: 3- or 4-way closure | (e) Bucket Weld: 3-way closure | (f) Salt Ridge: 3- or 4-way closure



Appalachian Basin

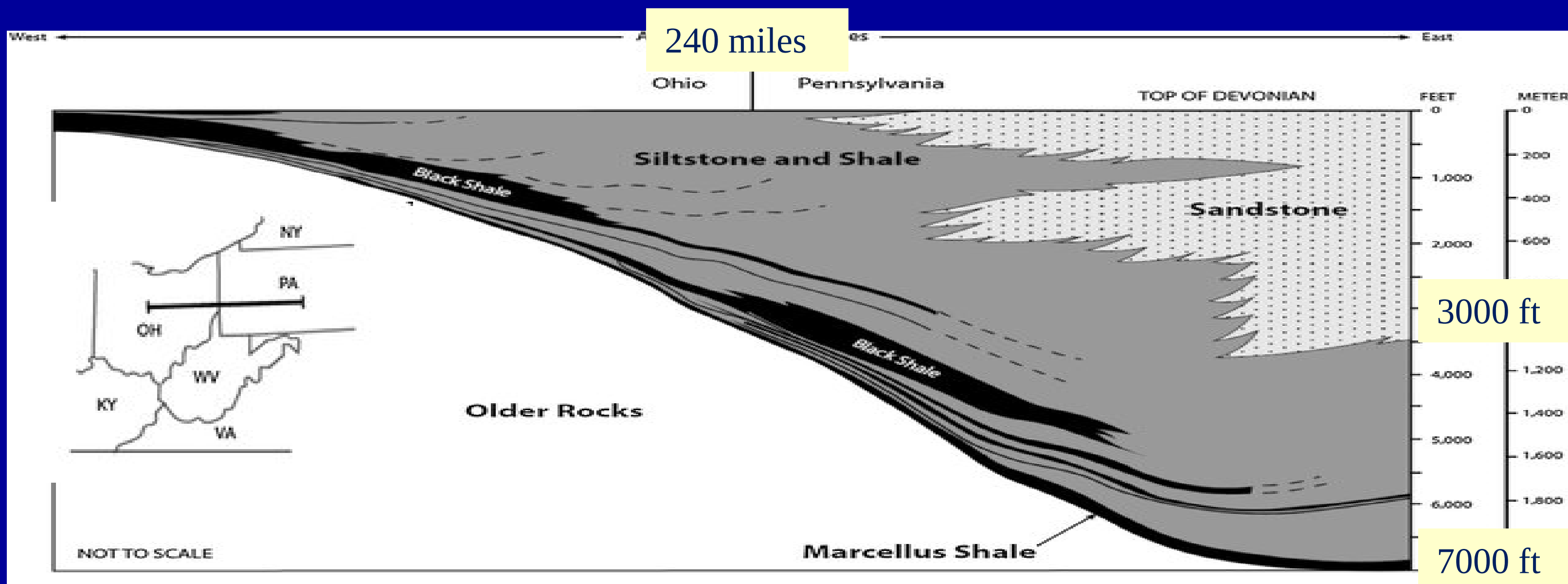
Drilling Depth to Base Marcellus

Appalachian Basin Cross Section

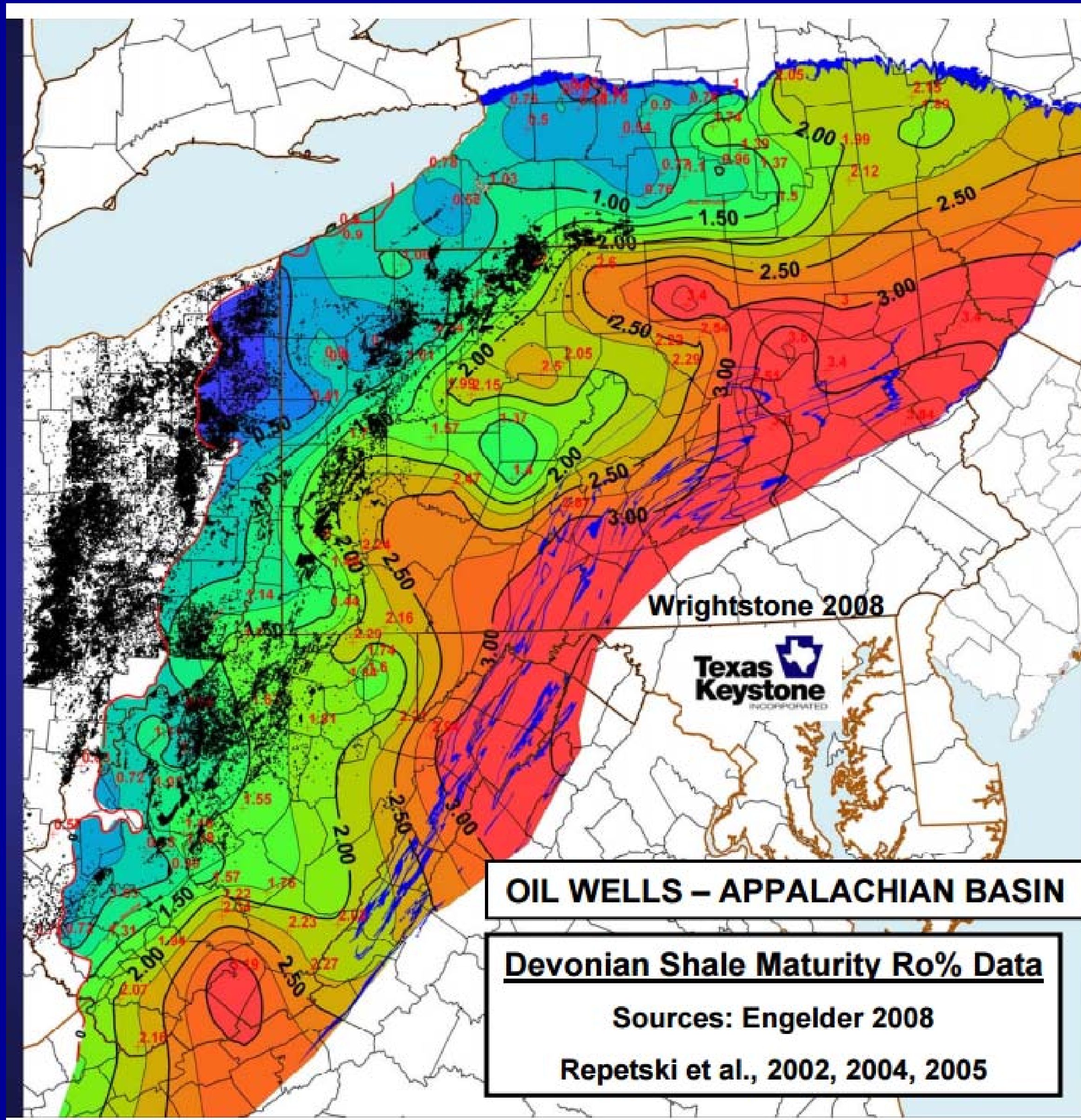
Foreland Basin

West

East



Soeder, DOE


Wrightstone 2008
Texas Keystone
OIL WELLS – APPALACHIAN BASIN
Devonian Shale Maturity Ro% Data
Sources: Engelder 2008
Repetski et al., 2002, 2004, 2005
1.00
1.50
2.00
2.50
3.00

Take Home Ideas

- A productive petroleum basin requires a mature, organic-rich source rock
- Conventional oil deposits depend on traps where migrated oil is concentrated
- Common structural traps are anticlines, tilted fault blocks, and tilted beds below unconformities
- A trap must have 3D closure to work
- Hydrocarbons are stacked by density in a trap
- Unconventional deposits depend only on having mature source rock that can be fracked.