THE ROLE OF GEOLOGY AND GEOPHYSICS

IN EXPLORATION AND PRODUCTION

Michael Ala

SPE Introduction to Exploration & Production
21 November 2017
London

PRESENTATION OUTLINE

- Introduction - nature of the Earth's crust, focusing on oil and gas bearing rocks.
- Geological time and and age distribution of the major global oil and gas reserves.
- The exploration cycle.
- Discovery appraisal, development and production.
- Petroleum system analysis:
  - Elements
  - Processes
- The role of geophysics.
- Well logging and its contribution to E & P activities.
- The unconventionals:
  - Shale oil
  - Shale gas

INTRODUCTION

- Petroleum occurs in the rocks that make up the earth's lithosphere or crust.
- Derived from the Latin words *petra* ('rock') and *oelum* ('oil').
- Definition of rock: An aggregate of crystals (or of non-crystalline materials) or grains.
- Geologists recognise three basic rock types:
  - Igneous
  - Metamorphic
  - Sedimentary

ROCK TYPES

Igneous rocks - form by the solidification of *magma* or molten material that rises fro the interior of the Earth. These are the 'parent' rocks of the other 2 groups. Example: *granite* **Metamorphic rocks** - form by the alteration of pre-existing rocks through an increase in temperature and pressure. The alteration occurs in the solid state which means that it does not involve melting. *Examples: marble and slate.*	'Economic basement' Non-petroliferous
Sedimentary rocks - form either by the cementing together or consolidation of fragments (grains) derived from pre-existing rocks, by direct precipitation from water or from the life processes of animals and plants. Examples: *sandstone, limestone, shale, chalk.*	Petroliferous

Igneous and metamorphic rocks are of high temperature origin, while sedimentary rocks form under low temperature (surface) conditions.

Oil and gas are associated with sedimentary rocks.

http://www.beg.utexas.edu/mainweb/publications/graphics/granite.htm

Granite hand specimen

Marshak, 2005

Gneiss hand specimen

- Bedding or stratification is the most important distinguishing feature of sedimentary rocks.
- This shows that they were deposited as discreet layers.

Murck & Skinner, 1999

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AAPG Explorer, June 2014

Photo by M Ala

Exposures of sedimentary rocks showing their bedded or stratified nature

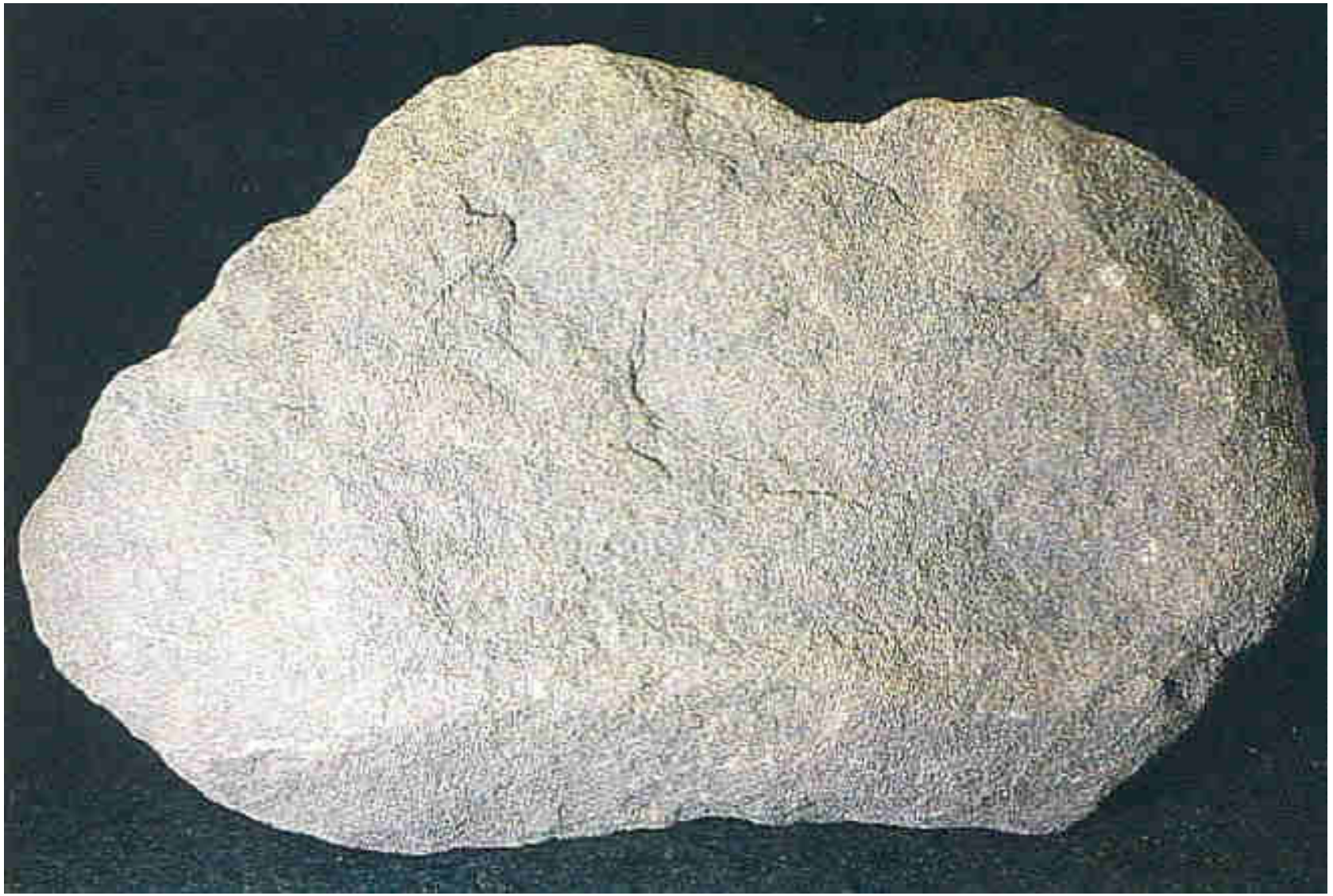


Photo by M Ala

A sandstone hand specimen. Note the granular texture of the rock

Photo by M Ala

Fossiliferous limestone

Photo by M Ala

A shale outcrop - note laminated (fissile) nature of the rock

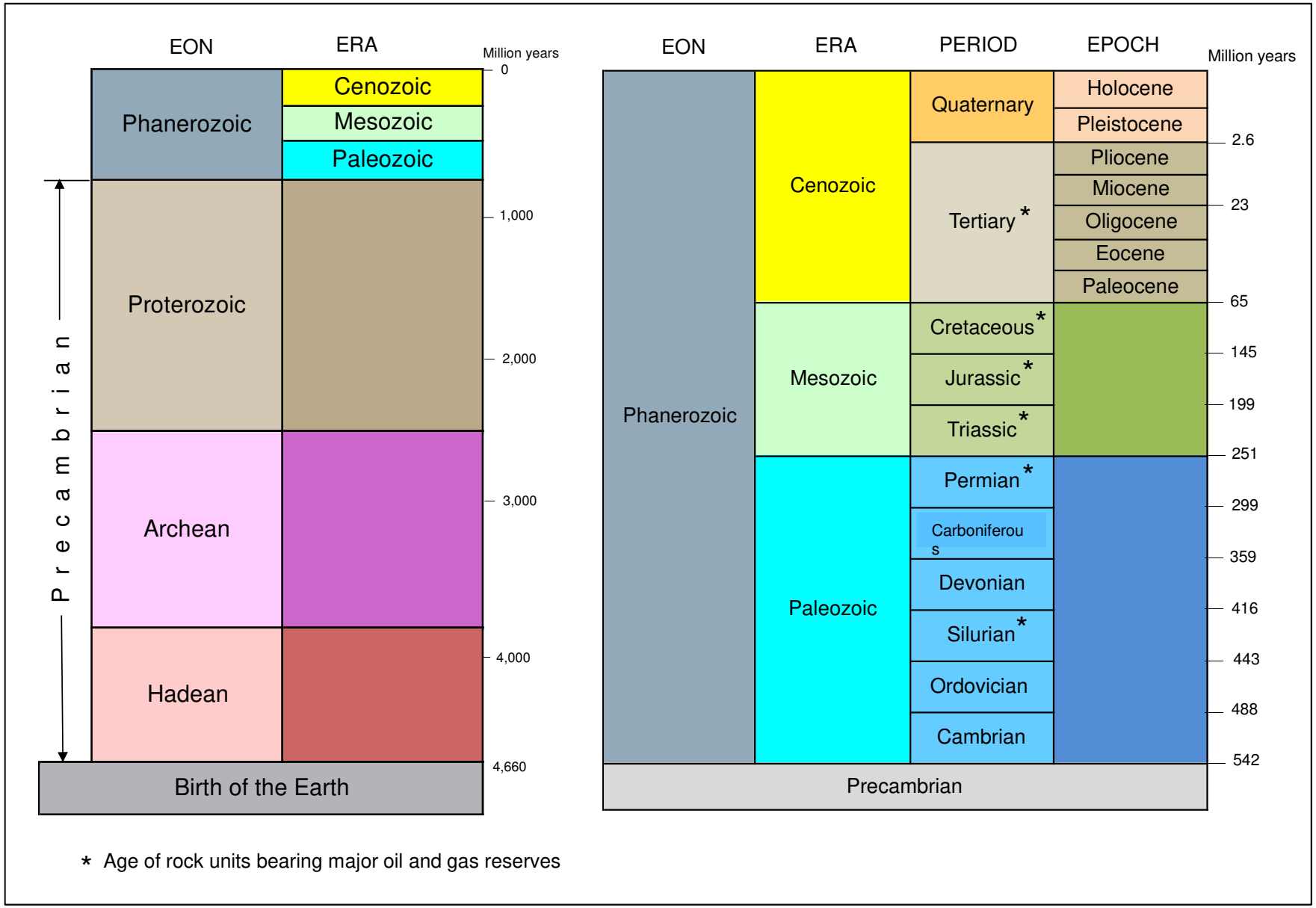
http://i1.mirror.co.uk

Chalk cliffs, southern England

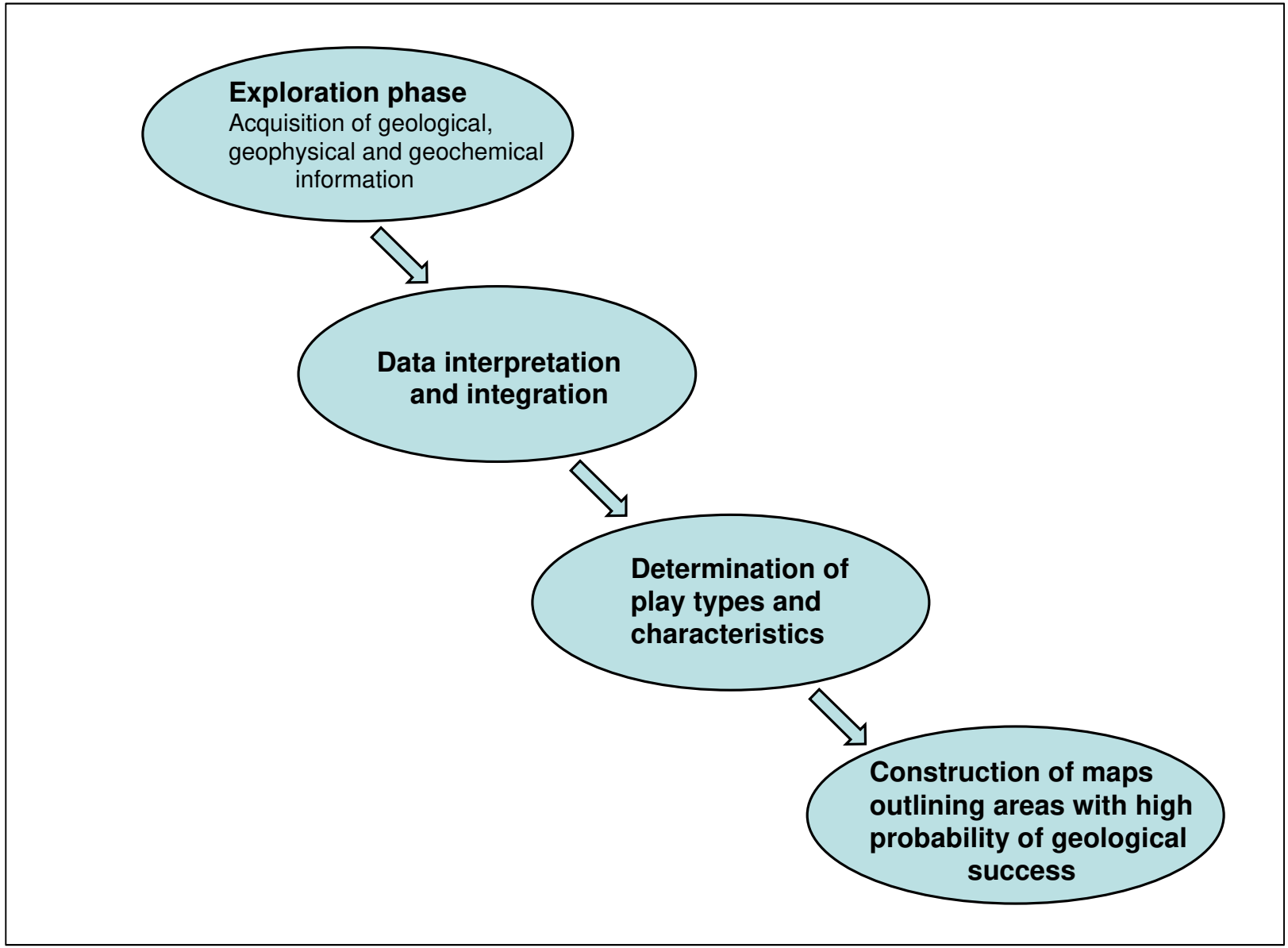
Name	Function in the petroleum system
Sandstones	Reservoir rocks
Carbonates	
Shales	Source and cap rocks (seals)
Evaporites	Cap rocks (seals)
Coal*	Potential source of gas (e.g. Southern North Sea)

* Organic carbon, not a sedimentary rock, *sensu stricto*

Common sedimentary rocks

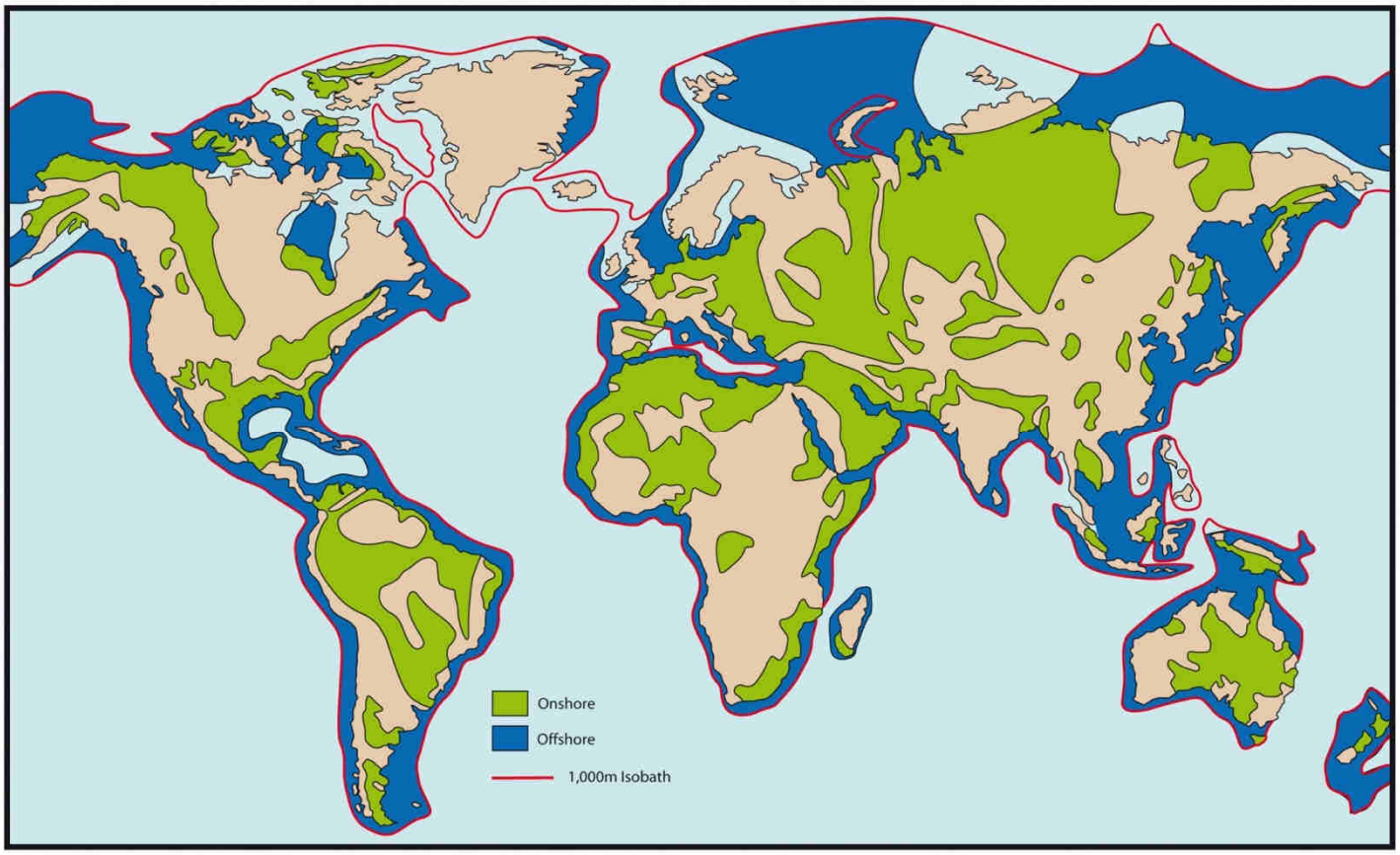


Geological time and and age distribution of the major global oil and gas reserves



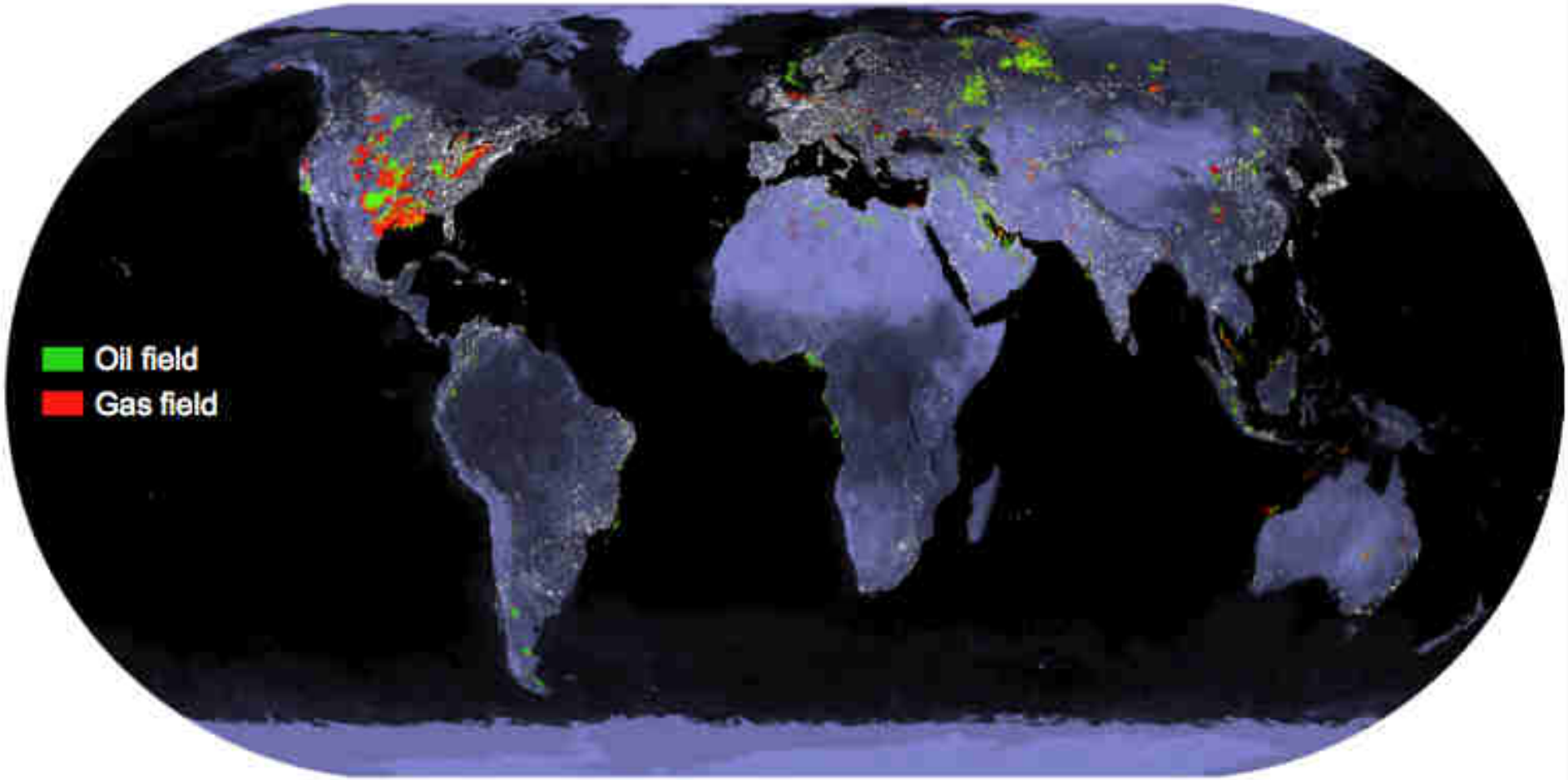
The exploration cycle: Steps involved in data acquisition, analysis and integration

- First step in an exploration programme: Identifying regions where oil and gas might be present
- Worldwide, oil and gas fields occur in ***sedimentary basins.***
- A sedimentary basin is a depression in the Earth's crust containing a large thickness of sedimentary rocks.

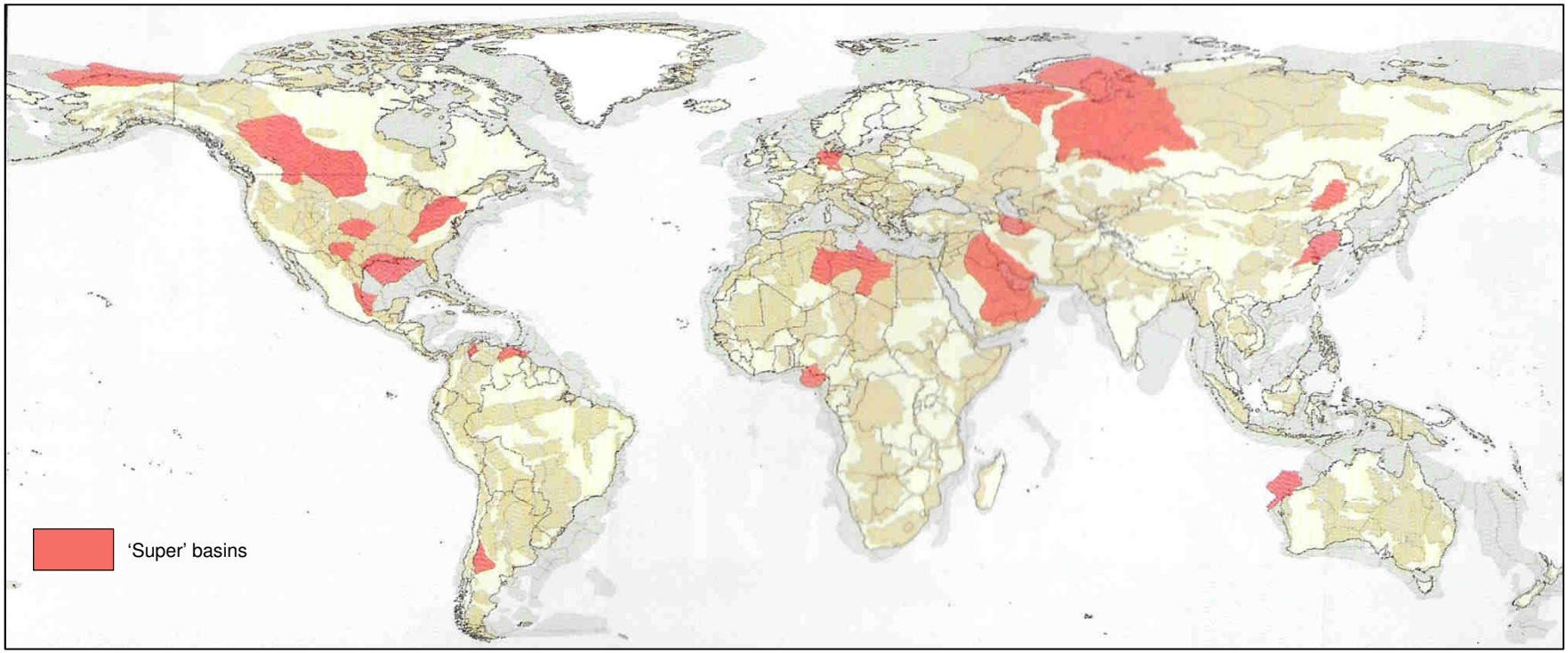


modified and redrawn from Kirby, 1977

Global distribution of the major sedimentary basins



Worldwide, oil and gas fields are associated with sedimentary basins



AAPG Explorer, July 2017

Locations of the world's 'super' basins

DISCOVERY APPRAISAL, DEVELOPMENT AND PRODUCTION

- In the event of a discovery, tests are carried out to assess its commercial viability.
- The discovery well is placed on temporary production for many hours.
- Flow rates, bottom hole and well head pressures are measured.
- Several more wells are drilled to appraise the discovery. These are referred to as appraisal wells and the objective is to:
  - Determine the aerial extent and hence the size of the hydrocarbon bearing reservoir.
  - Define the hydrocarbon volumes.
- Positive outcome of the tests will result in the discovery being declared a commercial field.
- A master development plan (MDP) is prepared and an integrated team of geologists, geophysicists and petroleum engineers will decide how best to develop the field to maximise the economic return from the asset.
- A number of development wells are drilled and the field is placed on production.
- From discovery to the field going on stream - 'first oil' - normally takes 5-7 years.
- It is possible to generate revenue by placing the the discovery and appraisal wells on production during the development drilling phase. This is referred to as the 'early production option'.

PETROLEUM SYSTEM ANALYSIS

PETROLEUM SYSTEM ANALYSIS

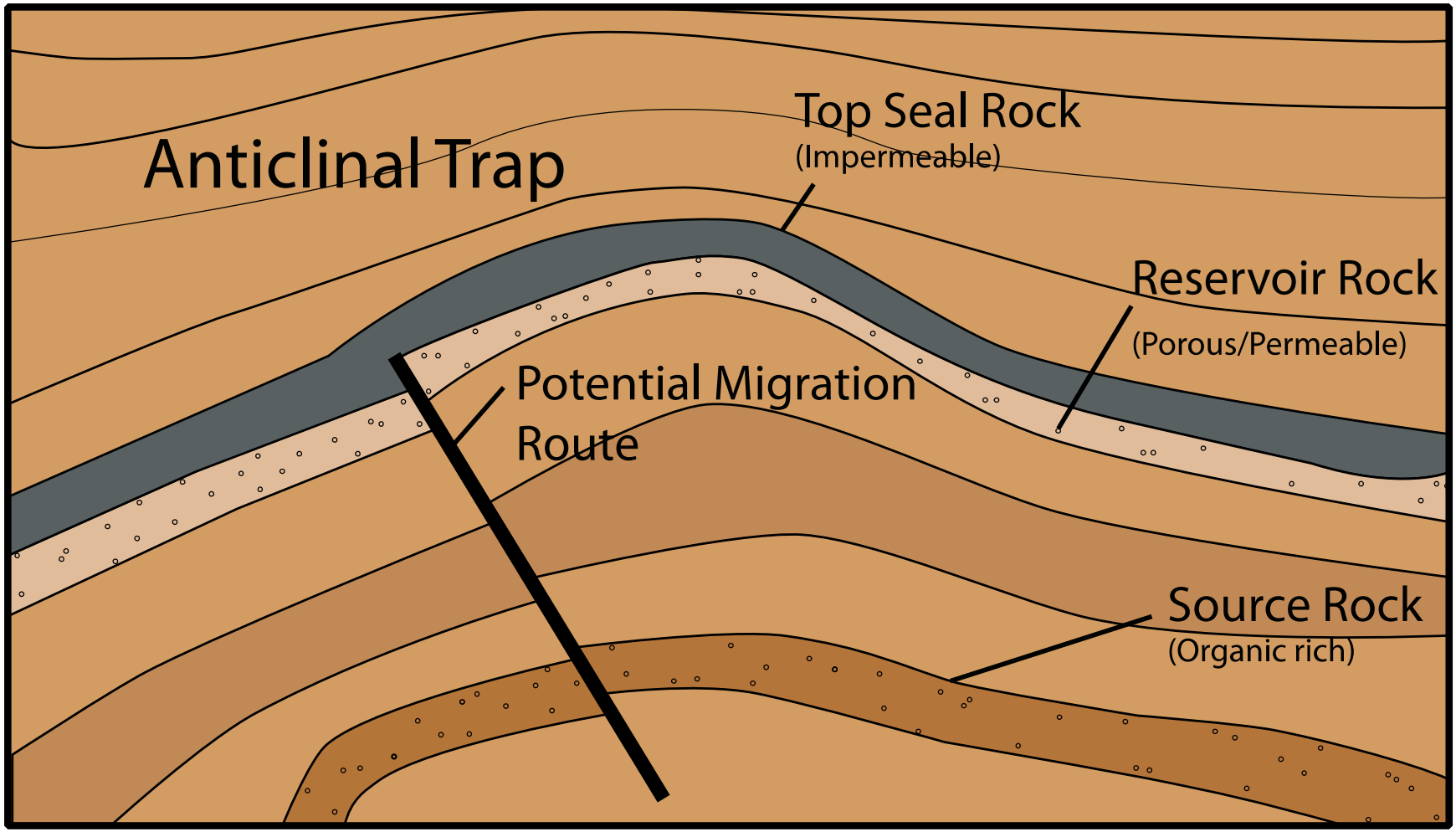
- Oil and gas fields are economically viable concentrations of hydrocarbons.
- Oil and gas formation is controlled by a number of factors referred to as **elements** and **processes**.
- **Petroleum system analysis:** Study of how these elements and processes interact to create hydrocarbon-bearing provinces.

ELEMENTS	PROCESSES
Source rock	Generation
Reservoir rock	Migration
Migration route	Accumulation
Seal or caprock	Preservation
Trap	Timing

Timing is critical: trap formation must predate migration

PETROLEUM SYSTEM ELEMENTS

- **Source Rock:** A rock with abundant hydrocarbon-prone organic matter.
- **Reservoir Rock:** A rock in which oil and gas accumulate:
  - Porosity: Space between rock grains in which oil and gas accumulate.
  - Permeability: Ease with which oil and gas can move through the pore spaces between the grains.
- **Seal or cap rock:** An impervious rock lying on top of the reservoir through which oil and gas cannot move effectively over time.
- **Migration Route:** Avenues through which oil and gas move from source rock to trap.
- **Trap:** A feature that arrests the migration process and causes oil and gas to accumulate.



Diagrammatic illustration of the elements of a petroleum system

- Sub aqueous environment.
- Surface waters must be oxic to support abundant organic life.
- Key factor: Preservation of the organic matter in the source rock. This requires an anoxic water/sediment interface, otherwise the organic matter becomes oxidised into CO_2 and water and will not be preserved.

Modified and redrawn from UKOOA and Natural History Museum, 1997

Exposure of an organic-rich shale (source rock), Yorkshire coast, NE England. Dark colour is due to the presence of organic matter in the rock.

Photo by M. Ala

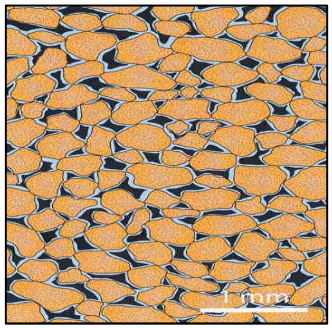
Conditions necessary for source rock deposition

PETROLEUM SYSTEM ELEMENTS

- **Reservoir Rock:** A rock in which oil and gas accumulate. It should be noted that oil and gas are not indigenous to the reservoir - i.e. they do **not** form *in situ.*

- Fundamental properties of reservoirs:

  Porosity (abbreviated to Φ) - space between rock grains in which hydrocarbons accumulate. Oil and gas do not occur in underground Lakes or rivers. Φ = (pore volume)/(bulk volume) and expressed as a %. It determines the storage capacity of the reservoir. It is up to40% in good reservoirs. The most common range: 10% - 20%. Some water is also present in addition to hydrocarbons in the pore spaces.

  Common reservoir rocks are sandstones and carbonates [limestone, $CaCO_3$, dolomite, $CaMg(CO_3)_2$ and chalk].

  Permeability (abbreviated to k) - the ability of a porous medium to transmit fluids and depends on the degree of connection between the pores. It is a complex quantity and is influenced by several factors, including the diameter of the passages or throats that connect the pores. It is measured in Darcy (D) or milliDarcy (mD) units. The most common range : 1 mD - 1,000 mD. Permeability controls well productivity.

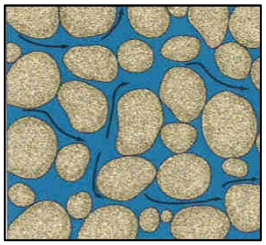
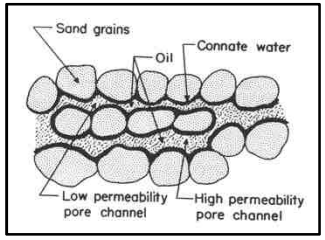
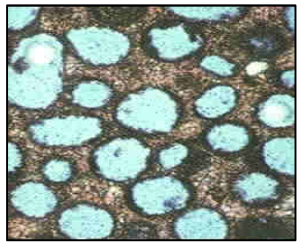


Illustration of permeability



Larger diameter pore throats characterise the high permeability channel



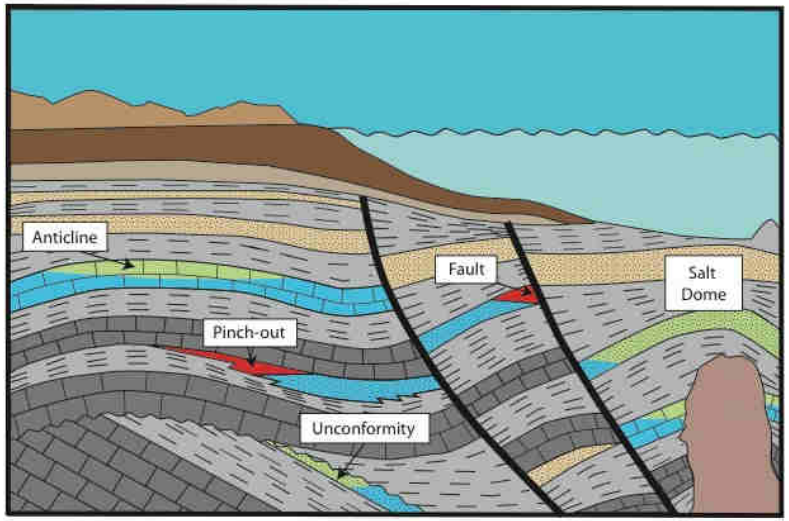
Isolated pore spaces. High porosity
but very low or no permeability

PETROLEUM SYSTEM ELEMENTS

- **Seal or cap rock:** An impervious rock lying on top of the reservoir through which oil and gas cannot move effectively over time.

- **Migration Route:** Avenues through which oil and gas move from source rock to trap.

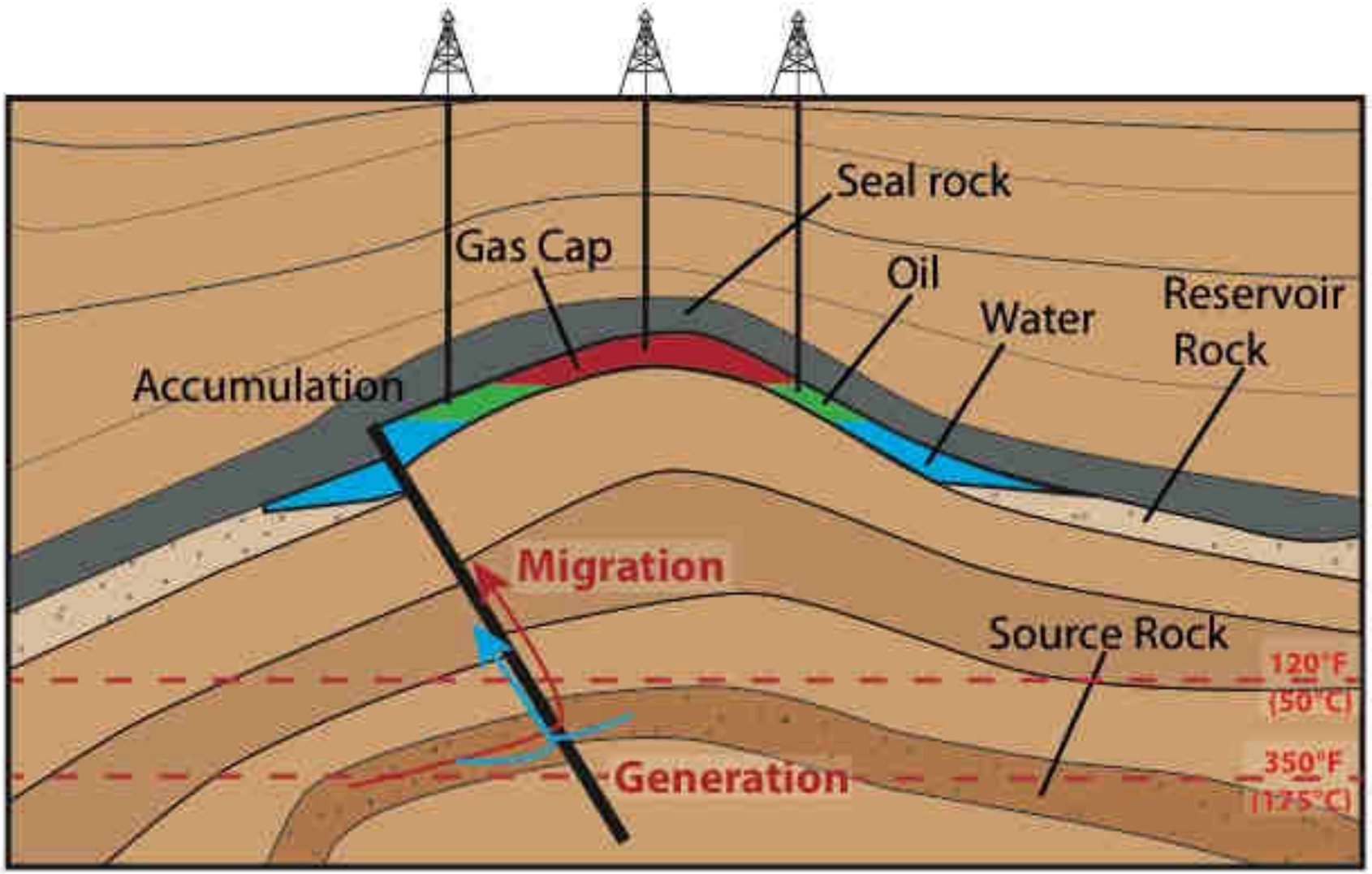
- **Trap:** A feature that arrests the migration process and causes oil and gas to accumulate. Caused by changes in the shape of the reservoir or faulting (structural traps), a change in rock type (stratigraphic traps) or a combination of these (combination traps).



Diagrammatic illustration of hydrocarbon trap types

PETROLEUM SYSTEM PROCESSES

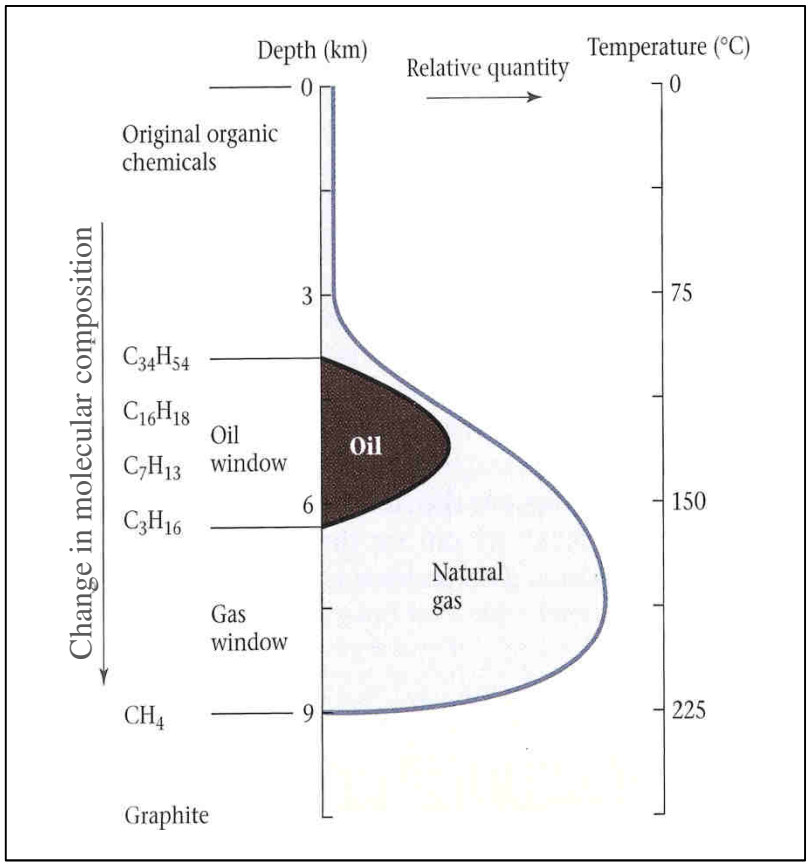
- **Generation:** Burial of source rock to a temperature and pressure regime sufficiently long to convert the organic matter into hydrocarbons.
- **Migration:** Movement of hydrocarbons out of the source rock toward and into a trap.
- **Accumulation:** A volume of hydrocarbons migrating into a trap faster than the trap leaks, resulting in an accumulation.
- **Preservation:** Hydrocarbons remains in reservoir; not biodegraded/contaminated nor the trap breached.
- **Timing:** Trap should form before or during hydrocarbon migration.



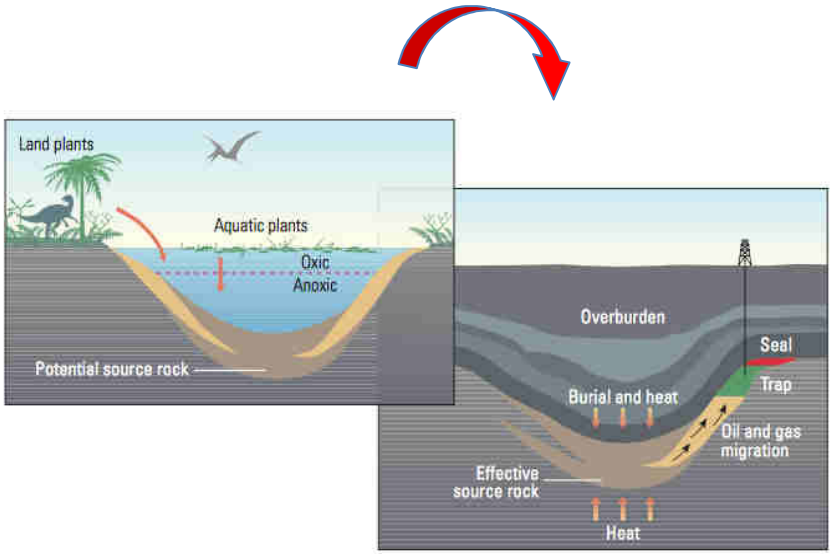
Diagrammatic illustration of the processes in a petroleum system

PETROLEUM SYSTEM PROCESSES

- Temperature is the single most important factor in the generation of hydrocarbons from organic matter.
- Progressively lighter hydrocarbons are formed with increasing temperature and depth.



Marshak, 2005



Al-Hajeri et al. 2009

Illustration of hydrocarbon generation, migration and entrapment

Hydrocarbon generation, migration and accumulation

THE ROLE OF GEOPHYSICS

SEISMIC DATA ACQUISITION

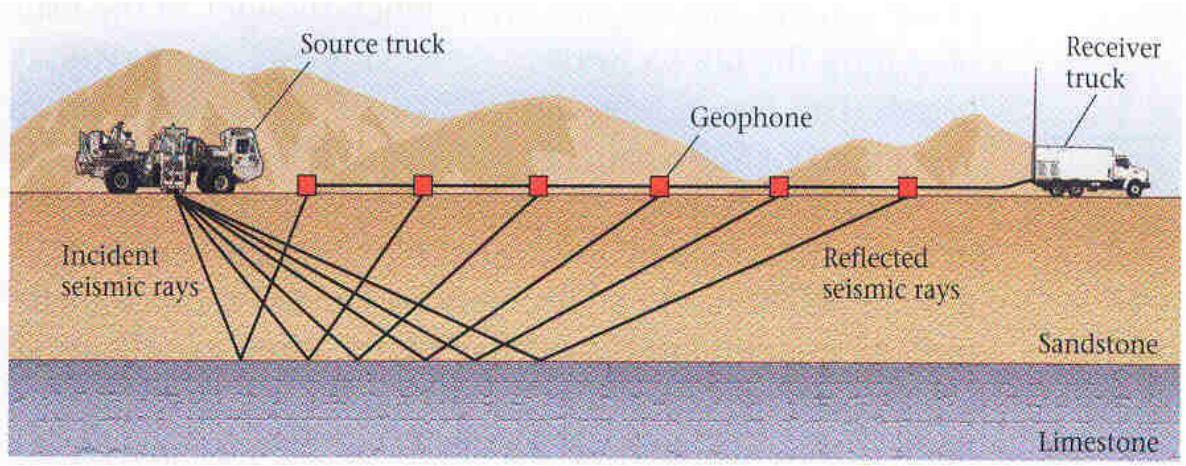
- Seismic waves generated at the surface propagate into the subsurface and are reflected back at subsurface rock boundaries at points where the layer properties change.
- These reflections from the subsurface are detected and recorded by receivers at the surface.
- On land, the receivers are called *geophones*, and are arranged in lines or in a grid.
- Offshore, the receivers are called *hydrophones* and are towed behind the survey vessel.
- The seismic source is dynamite and truck mounted vibrators on land and air guns offshore.

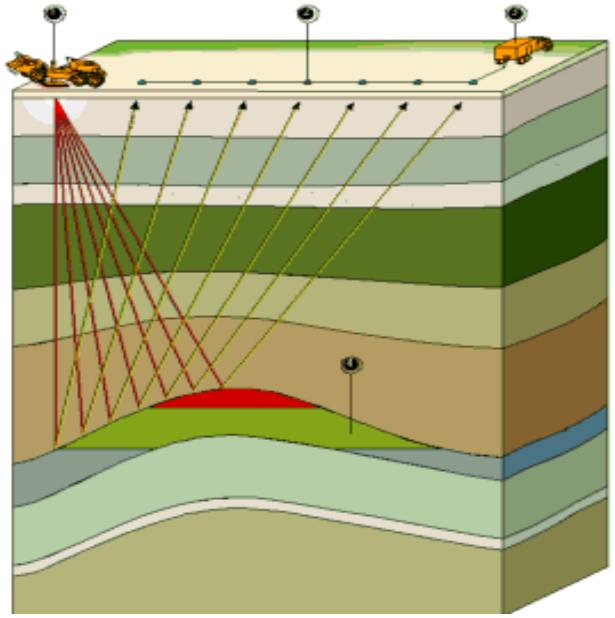
www.edgo.com

Seismic survey trucks

www.pgecurrents.com

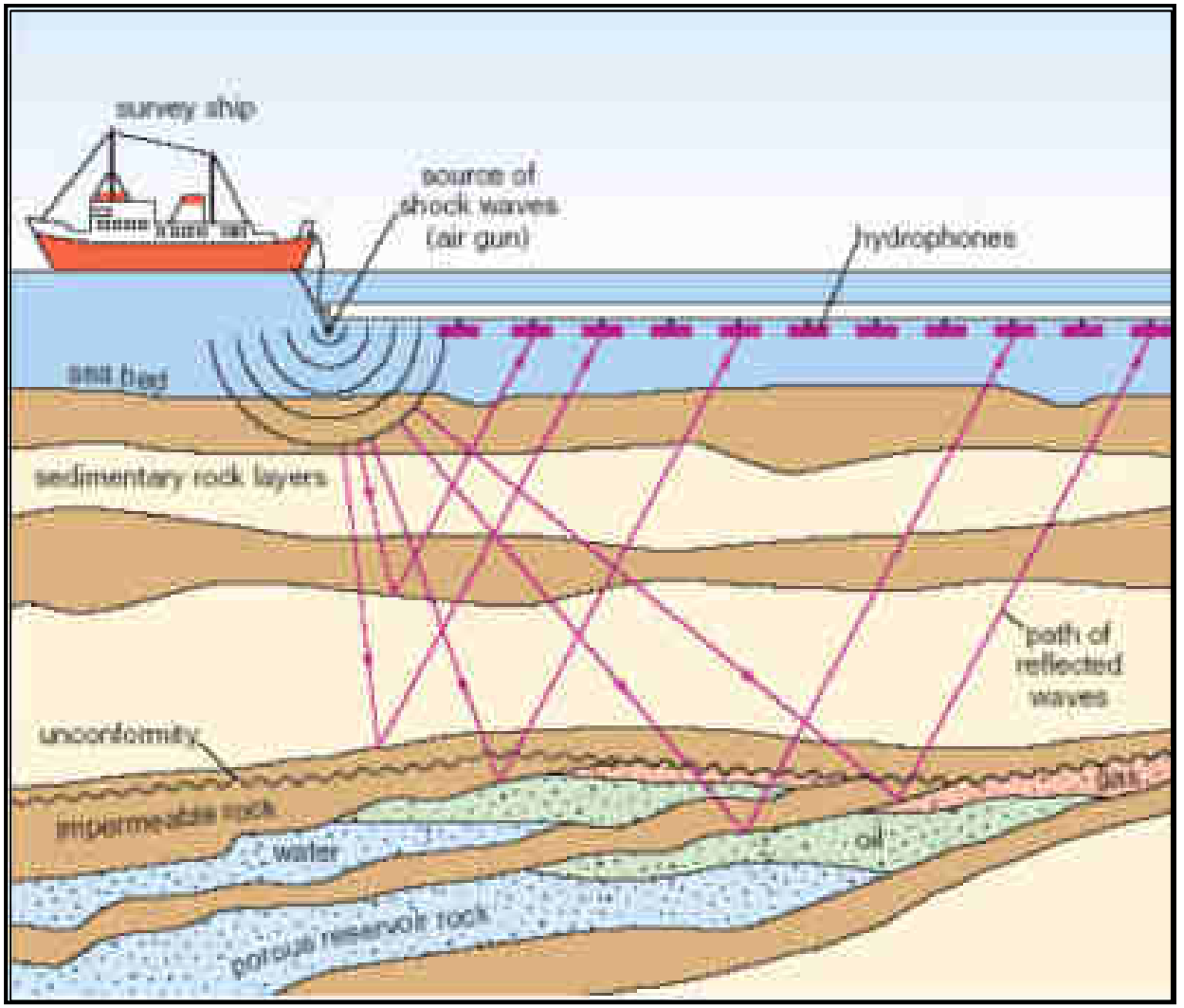
A vibroseis truck





Principle of onshore seismic data acquisition

Marshak, 2005

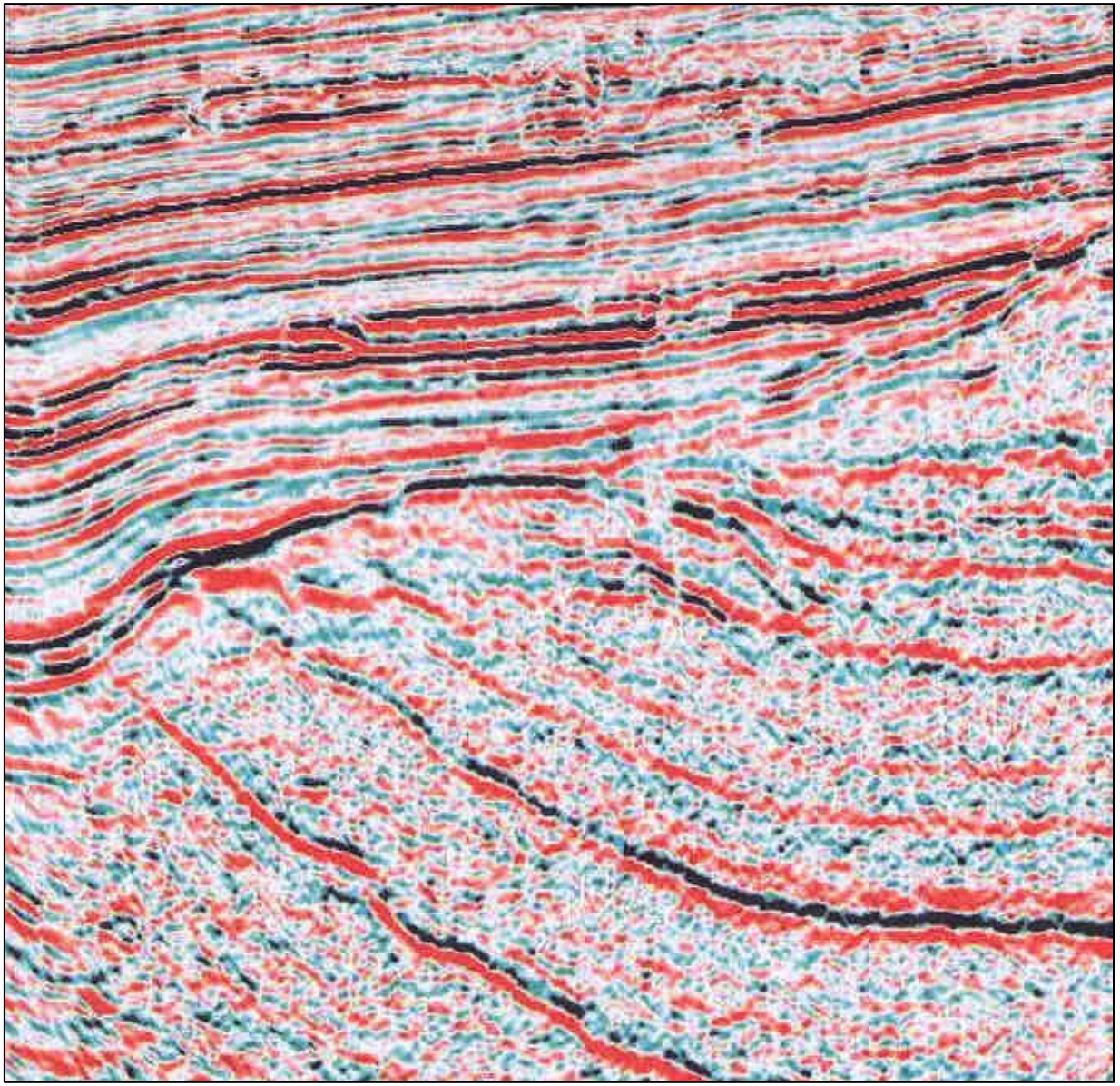


www.rigzone.com

Marine seismic data acquisition

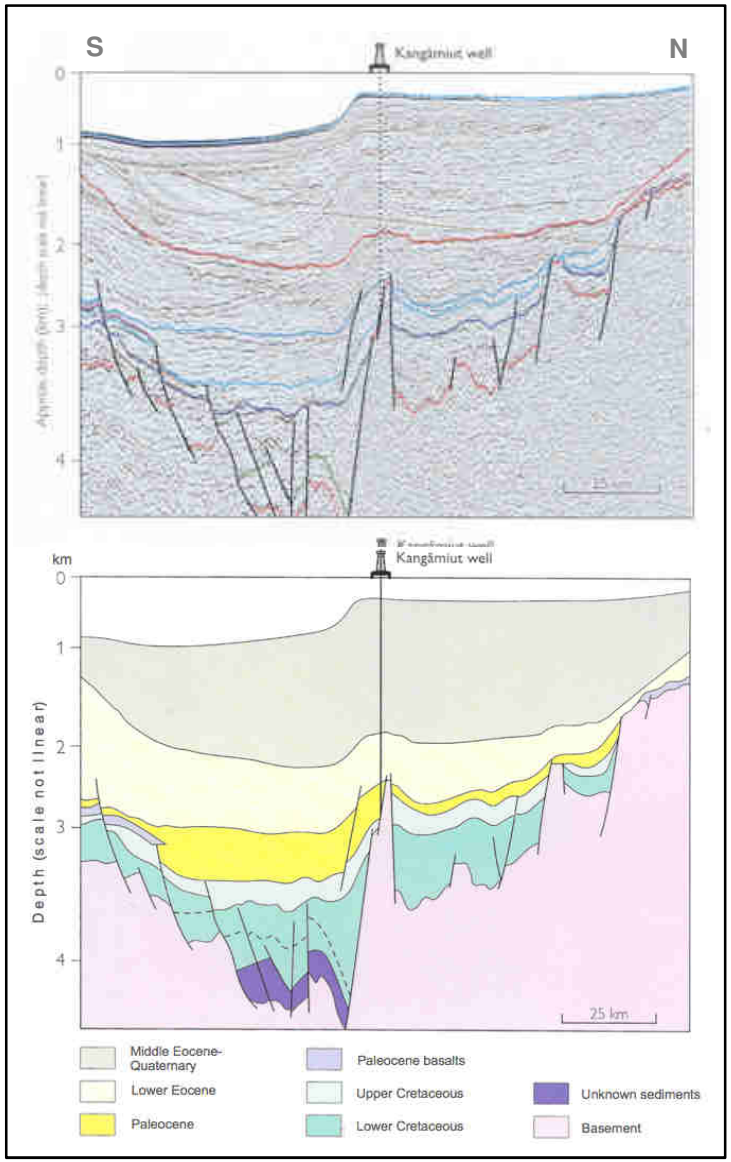
www.iagc.org

A marine seismic survey operation



GEO EXPro, 2008

Uninterpreted seismic section, offshore Norway

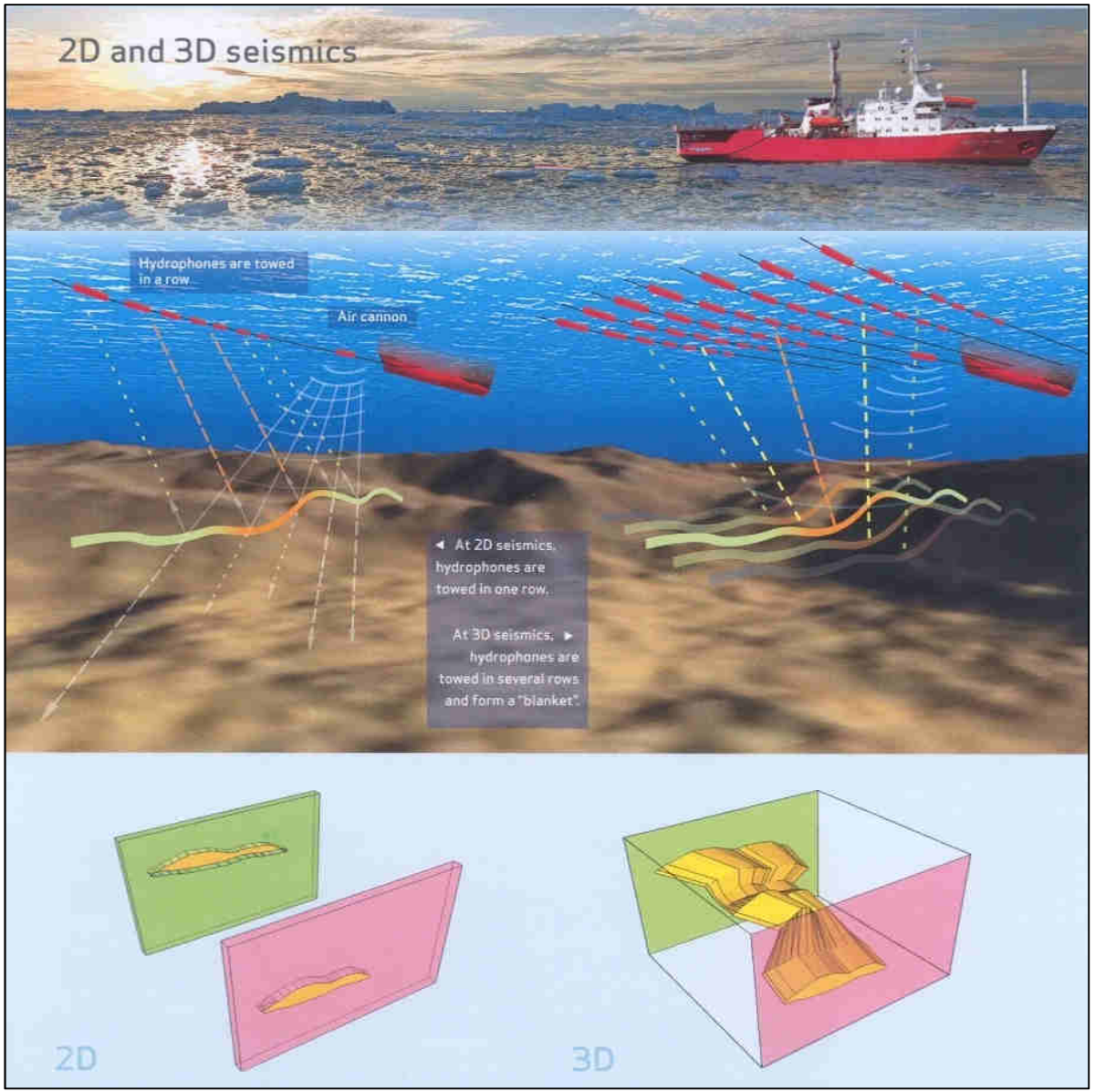


Henriksen, 2008

Example of the conversion of an interpreted seismic section into a geological cross section, offshore west Greenland

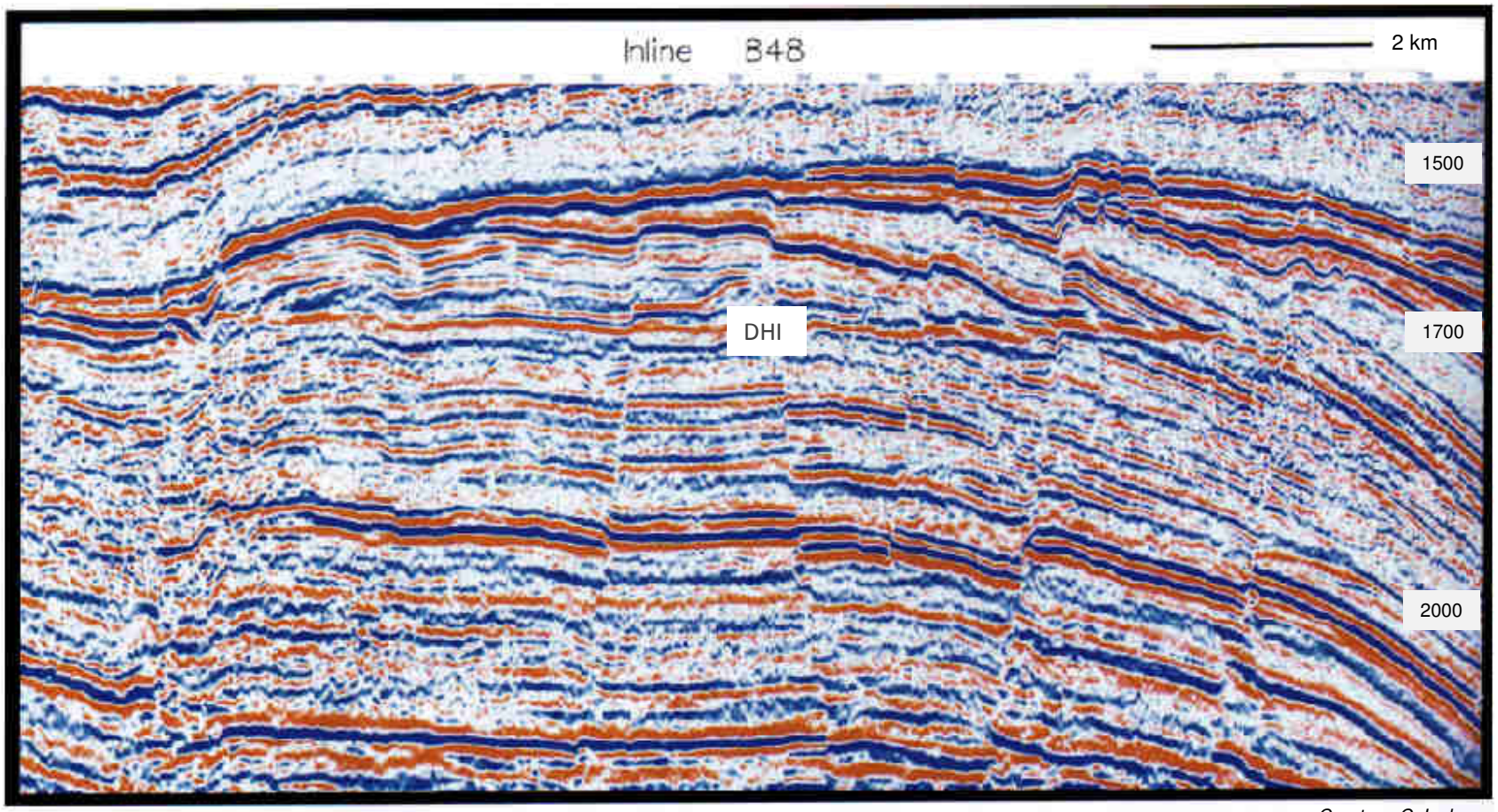
TYPES OF SURVEY

- **2D surveys** use 2-3 km grid spacing and provide regional coverage.
- **3D surveys** use 20-30 m grid spacing. Thousands of geophones/hydrophones are deployed and provide detailed information to define drilling objectives.
- **4D surveys** - the '4' in 4D is the time dimension. A 4-D survey means that at least two 3-D surveys have been run at different times over the same area, usually a field. The reflection characteristics of a reservoir change through time due to changes in fluid saturations. 4D surveys can therefore be used to monitor fluid movements in a reservoir.



Bureau of Minerals and Petroleum, Greenland, 2009

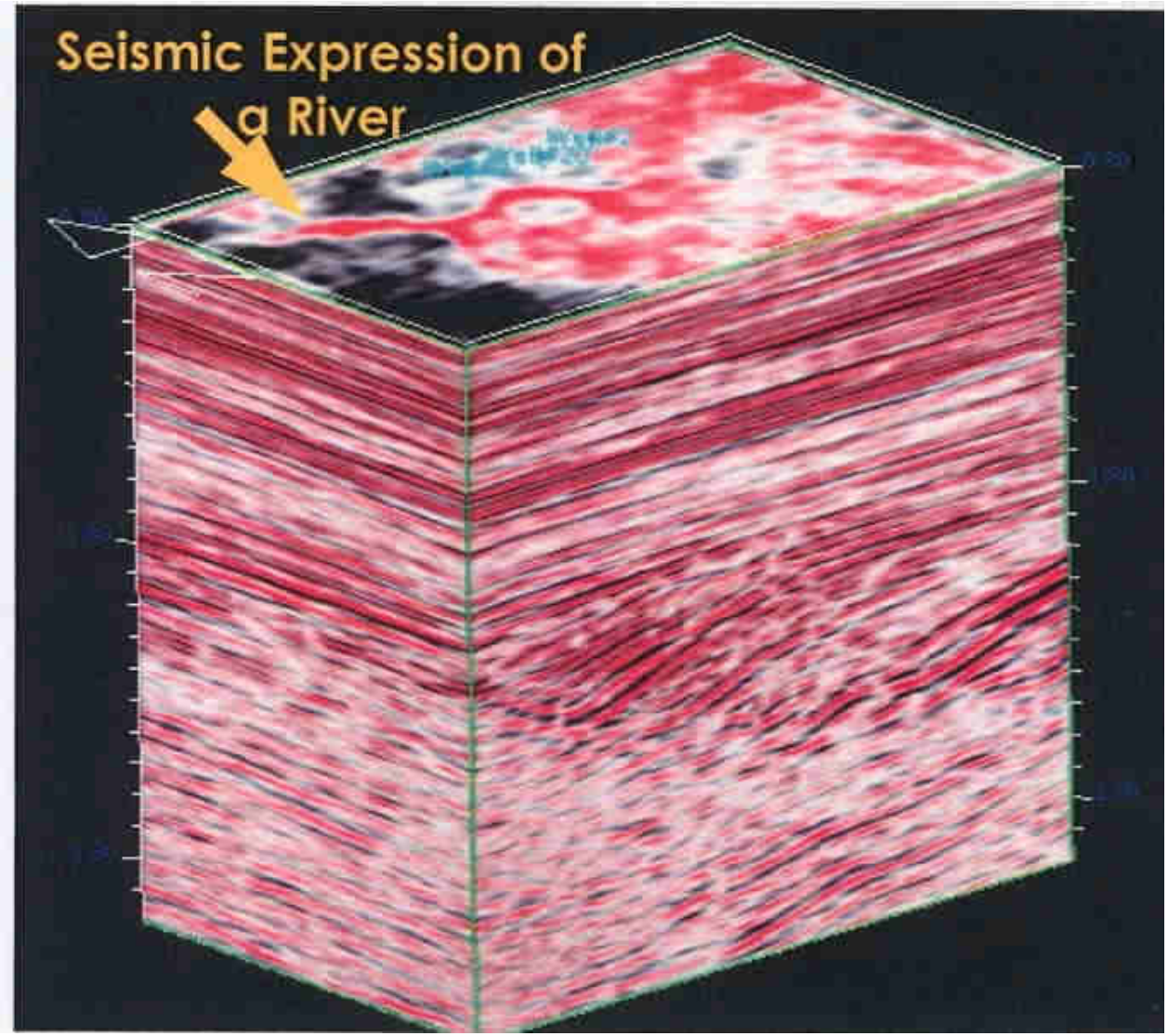
Comparison between the results of 2D and 3D seismic data



Courtesy C Jackson

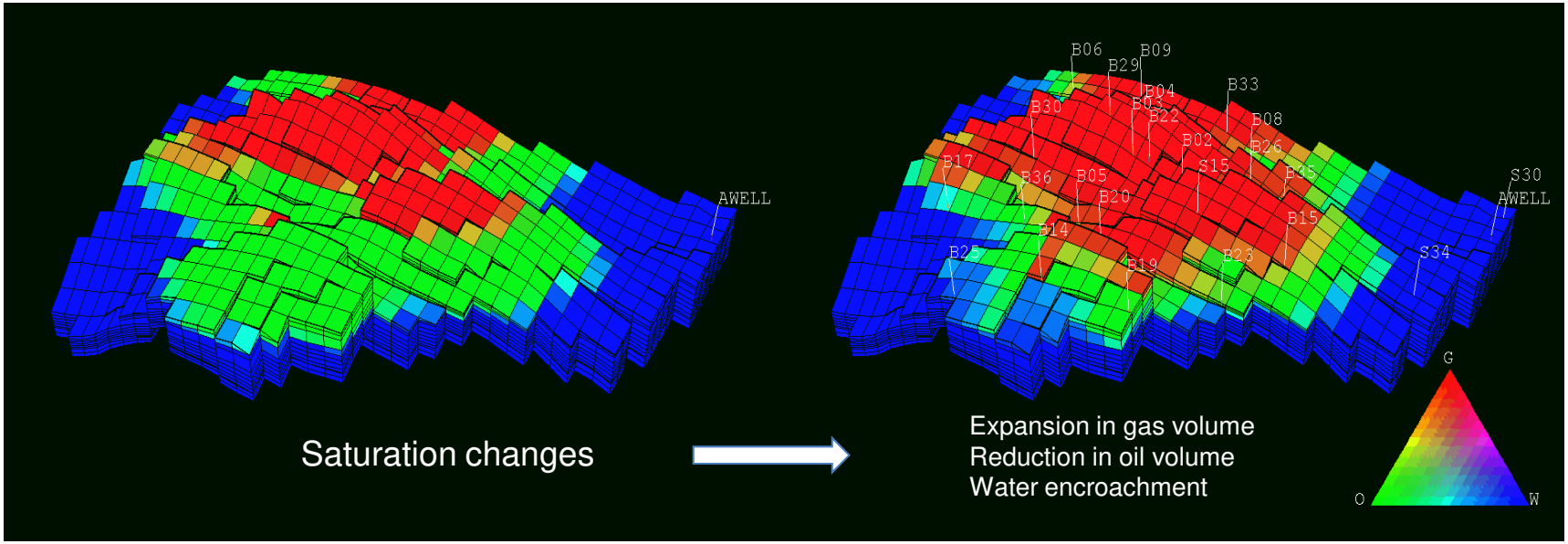
DHI: Direct hydrocarbon indicator

Seismic section across the Troll Gas Field, offshore Norway, showing extensive faulting and a 7-km-long flat spot at 1700 ms, representing the GWC



Mapping of a river channel by 3D seismic interpretation.

FIELD SIMULATION STUDIES USING SEISMIC DATA



Modifications in the reflection characteristics of a reservoir through time resulting from variations in fluid saturations allow such changes to be monitored

WELL LOGGING

WHAT IS A *LOG?*

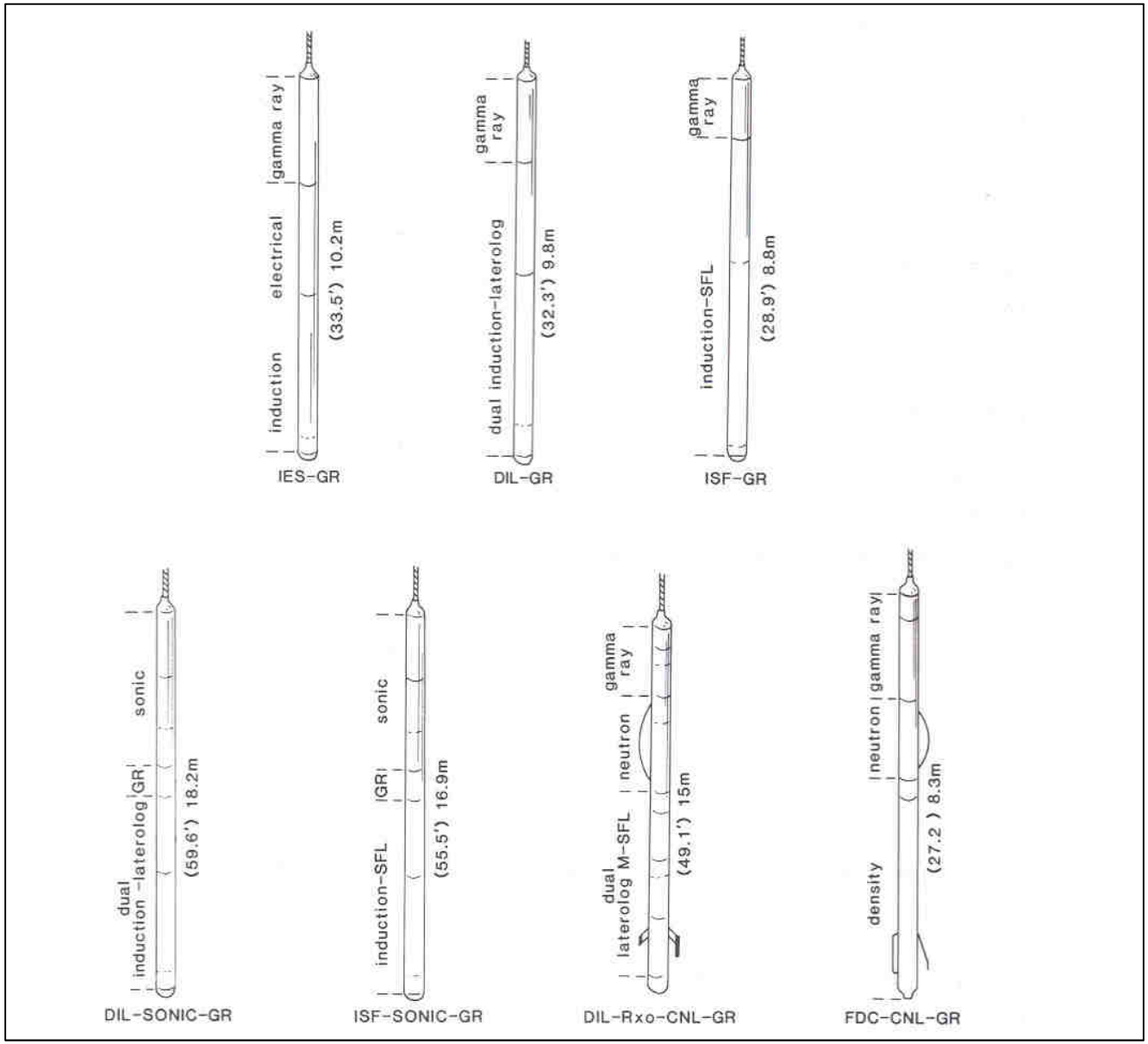
A continuous recording versus depth of a set of curves representing the electrical, acoustic, radioactive and nuclear magnetic resonance properties of the formations penetrated in wells.

Two broad categories:

- **Open hole**
  - Logs recorded before any casing is run.
  - Provide data on lithology (rock type), porosity, and fluid characteristics.
  - Used by both petroleum geoscientists and engineers.

- **Cased hole**
  - Also referred to as *production logs* - run in cased holes.
  - Measure flow rates in production wells.
  - Monitor the quality of the cement bonding the casing to the borehole wall.
  - Used primarily by petroleum engineers.

Logging tools are attached to a cable or *wireline* and lowered into the borehole. The cable also carries the electric current which powers the tools.

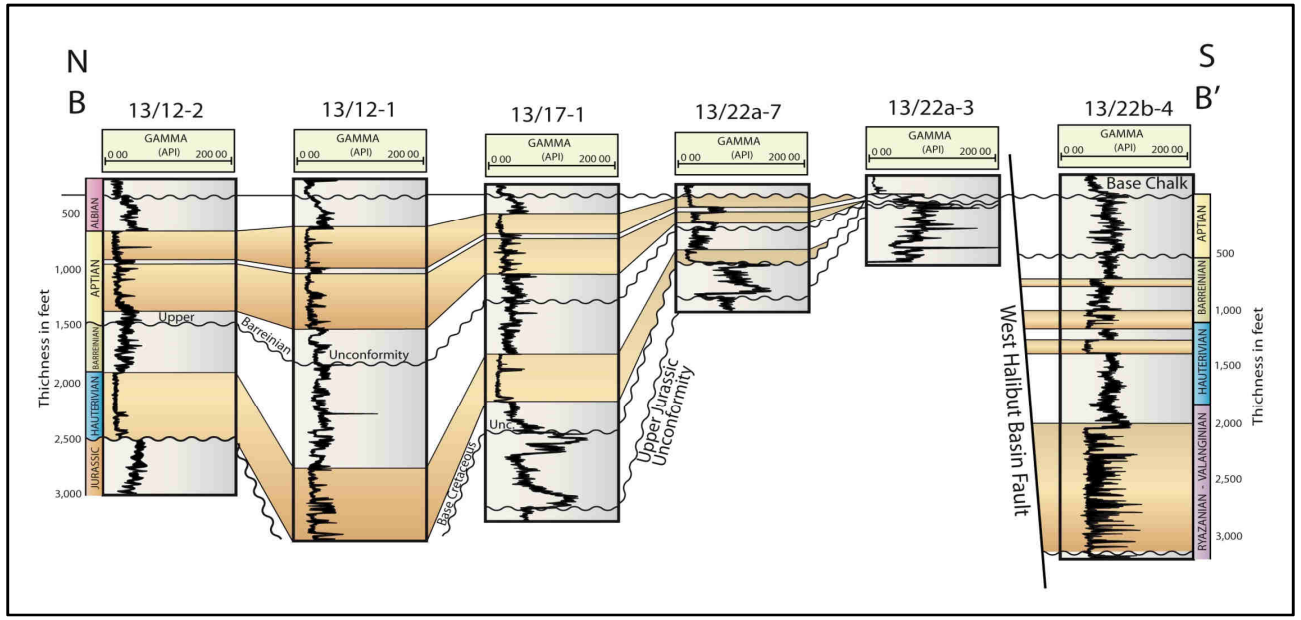


Schlumberger

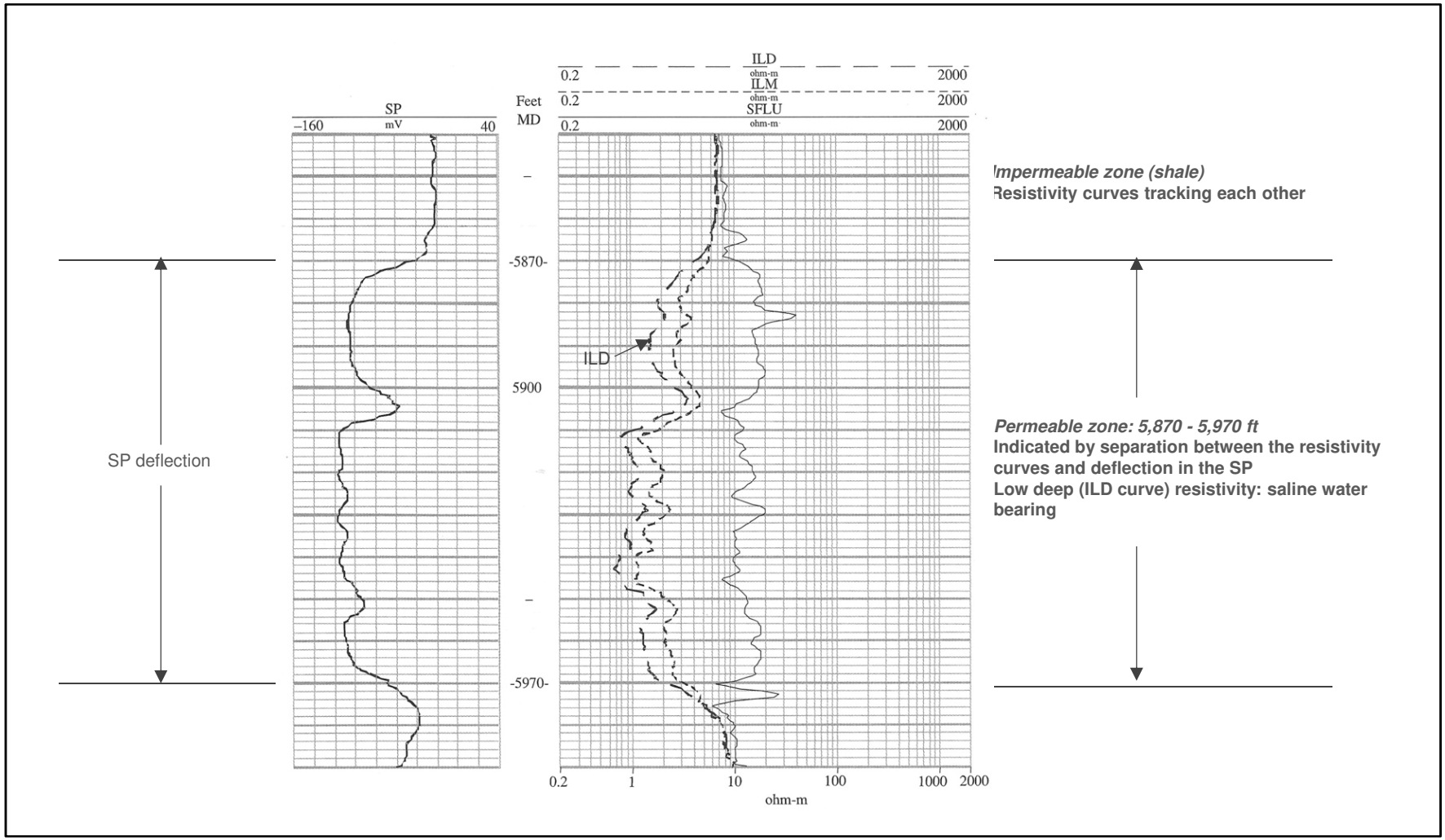
Logging tools

APPLICATIONS

- Identification of permeable beds and their boundaries.
- Identification of the pore fluids.
- Correlation of subsurface strata, showing lateral variations in rock type and thickness of a given layer, normally the reservoir in field studies.

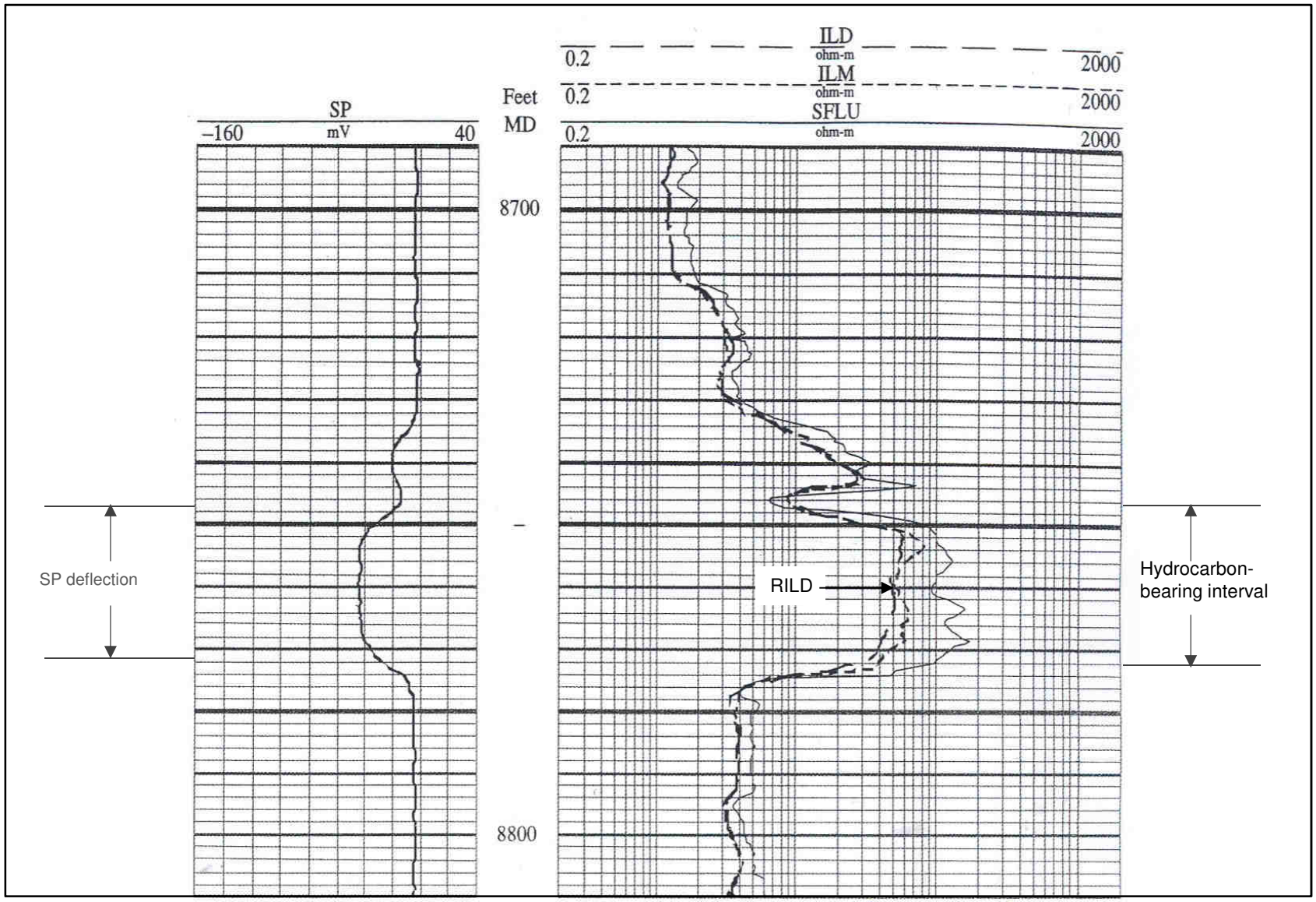


- Quantification of porosity (Φ).
- Calculation of water saturation in the reservoir.
- Determination of hydrocarbon saturation in the reservoir - an important parameter in reserves estimation.



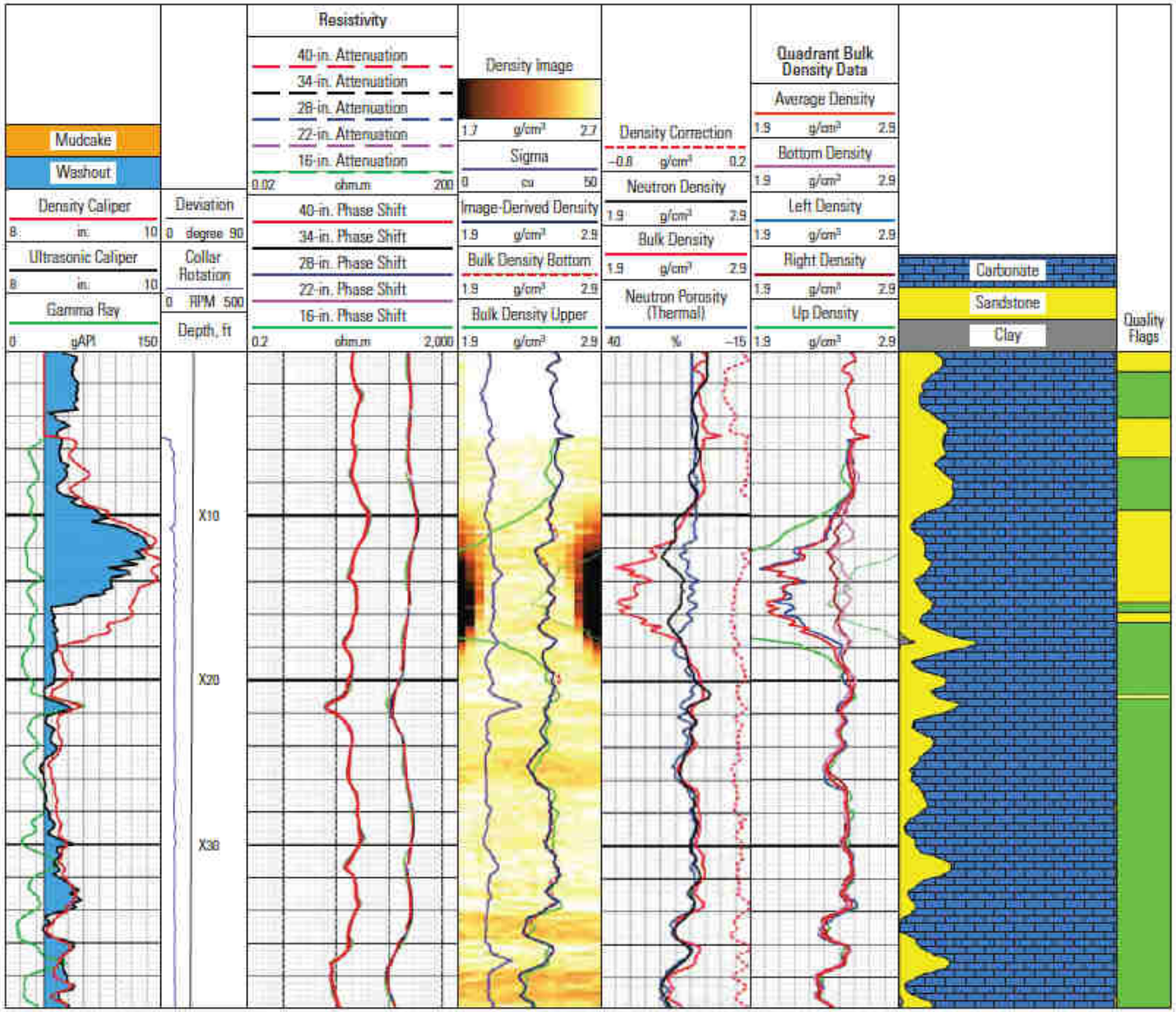
Asquith & Krygowski, 2004

A suite of electric logs showing permeable and impermeable formations



Asquith & Krygowski, 2004

A suite of electric logs showing a hydrocarbon bearing interval

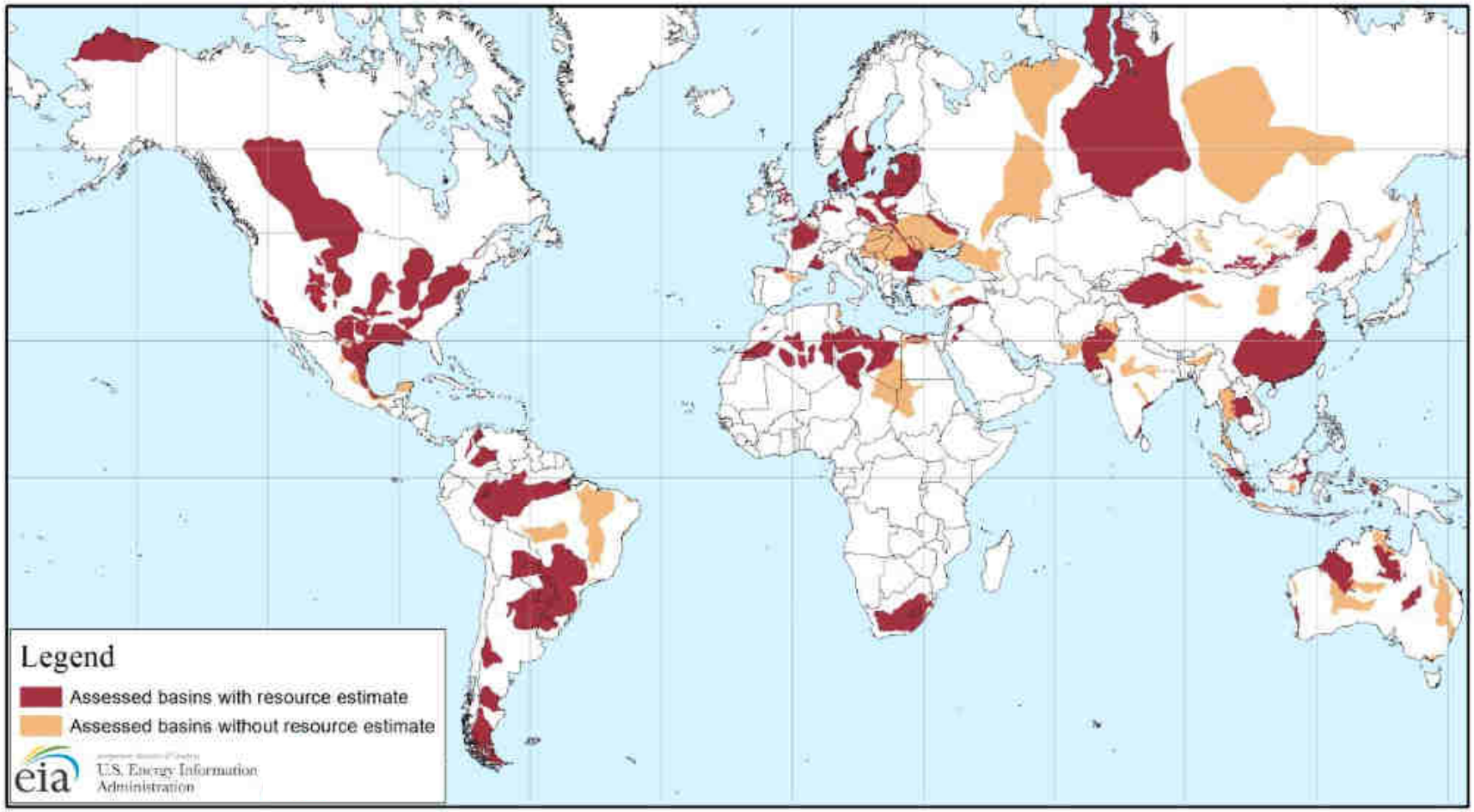


Allioli et al, 2013

Example of a computer processed log interpretation

THE UNCONVENTIONALS

Definition: *Oil and gas deposits that are not stored in pore spaces and in the reservoir and are not commercially recoverable by conventional drilling and production methods.*

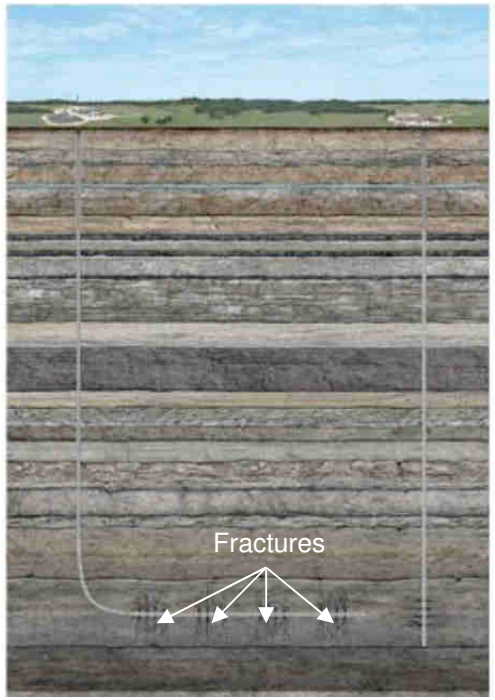


http://www.eia.gov/analysis/studies/worldshalegas/pdf/overview.pdf

Global distribution of shale oil and shale gas formations, as of May 2013

PRODUCTION OF OIL AND GAS FROM SHALE

- Producing hydrocarbons from shale is a water intensive process: On average, some 20 million litres of water are forced under pressure into each well, combined with large volumes of sand to help keep the fractures open, plus 200,000 litres of chemical additives.
- A good oil well may produce up to 700 b/d initially, but that may drop to 100 b/d by the end of the first year and the production remains at this level for the next two or three decades.
- New wells constantly need to be drilled in order to maintain production and a sustained high oil price is therefore required for the economic viability of the operations.
- Hydrocarbon production from shale is still a North American phenomenon and increasing supplies of oil and gas from this source have transformed the American energy landscape - the US is now a gas exporter.



http://energy.gov/fe/shale-gas-101

http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm

Distribution of the US gas basins and plays, May 2013

Technically Recoverable Shale Oil Resources (Billion Barrels)	
1. Russia	75
2. US	48
3. China	32
4. Argentina	27
5. Libya	26
6. Australia	18
7. Venezuela	13
8. Mexico	13
9. Pakistan	9
10. Canada	9
11. Others	65
TOTAL	**335**

Technically Recoverable Shale Gas Resources (TCF)	
1. US	1,161
2. China	1,115
3. Argentina	802
4. Algeria	707
5. Canada	573
6. Mexico	545
7. Australia	437
8. South Africa	390
9. Russia	285
10. Brazil	245
11. Others	1,535
TOTAL	**7,795**

http://www.eia.gov/analysis/studies/worldshalegas/pdf/overview.pdf

Technically recoverable shale oil and shale gas resources as of May 2013