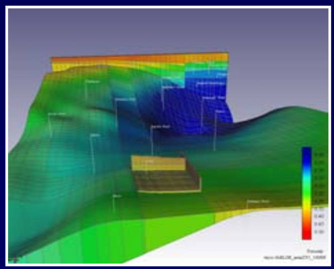
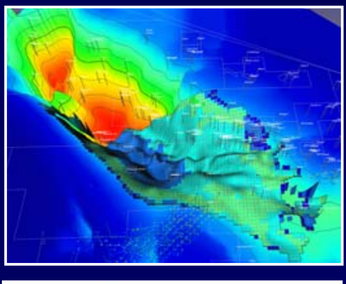
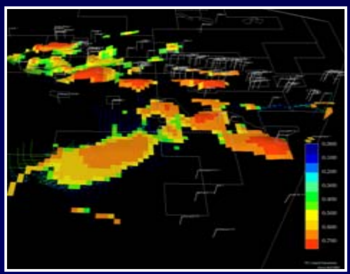
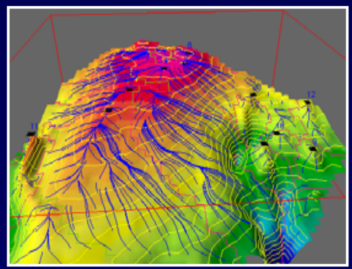
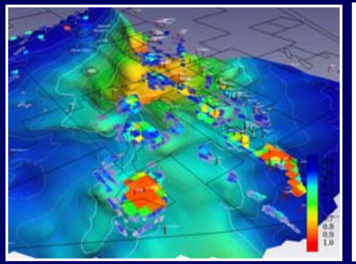
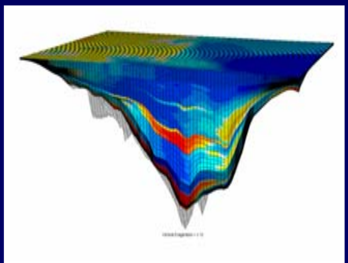
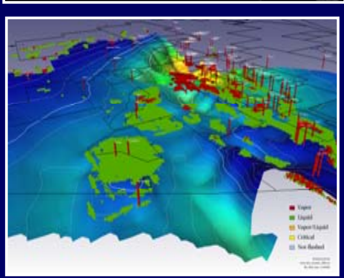
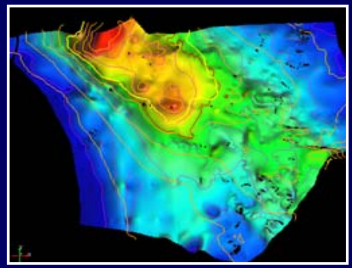
Basin Modelling Training:
Introduction

Topics:

Introduction to Basin Modelling

- Petroleum System Concept
- 1D/2D/3D Models
- Applications

Burial Subsidence Analysis

- Sedimentary loading & Compaction
- Tectonic Subsidence
- Hands-on: Burial History

Thermal History

- Heat Sources & Sinks
- Rock Thermal Properties
- Thermal & Maturity Parameters
- Hands-on: 1D Maturity Modelling

Pressure & Fluid Flow Modelling

- Effective Stress & Permeability
- Overpressure Mechanisms
- Geopressure Prediction

Hydrocarbon Generation

- Source Rock Parameters
- Kerogen Kinetics
- Hands-on: HC Generation

Hydrocarbon Migration Entrapment & Preservation

- Raypath, Darcy, Invasion Percolation
- Biodegradation & Cracking

Case Studies

- Malay Basin
- West Baram

Types of Basin-scale Modelling

- **Basin infilling** , e.g., stratigraphic modelling
- **Fluid transport** , e.g., hydrogeologic/hydrodynamic
- **Tectonic deformation**, e.g., structural modelling
- **Petroleum system** , e.g., basin modelling

A <u>Petroleum System</u> is defined as a natural system that encompasses a pod of active source rock and all related oil and gas and which Includes all of the geologic elements and processes that are essential if a hydrocarbon accumulation is to exist.

(Leslie B. Magoon and Wallace G. Dow, AAPG Memoir 60)

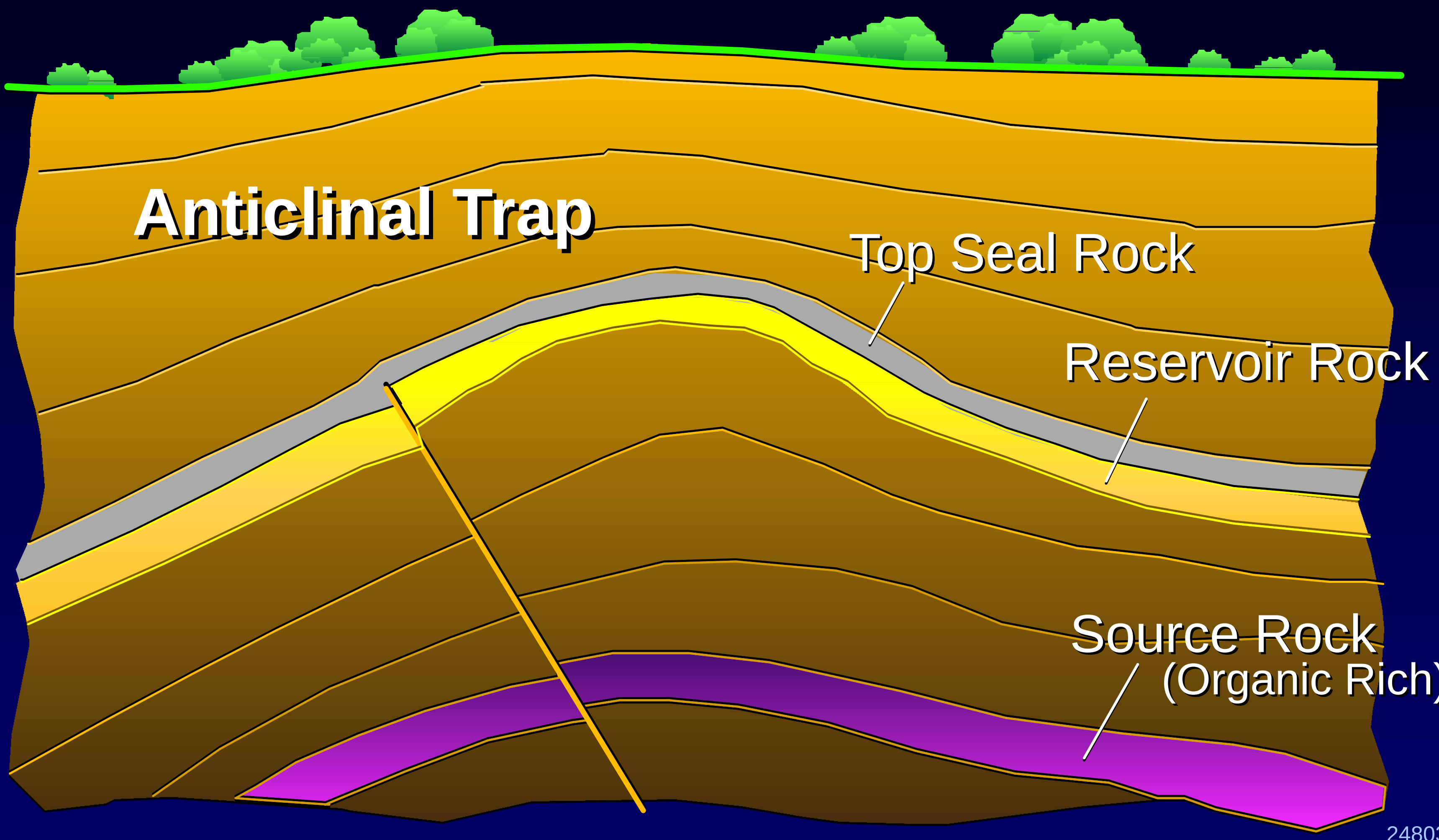
<u>Elements</u>

- Source Rock
- Migration Pathways
- Reservoir Rock
- Seal Rock
- Trap

<u>Processes</u>

- Generation
- Migration
- Accumulation
- Preservation

Petroleum System Elements



Source: AAPG

Petroleum System Elements

- **Source Rock** - A rock with abundant hydrocarbon-prone organic matter

- **Reservoir Rock** - A rock in which oil and gas accumulates:
  - ***Porosity*** - space between rock grains in which oil accumulates
  - ***Permeability*** - passage-ways between pores through which oil and gas moves

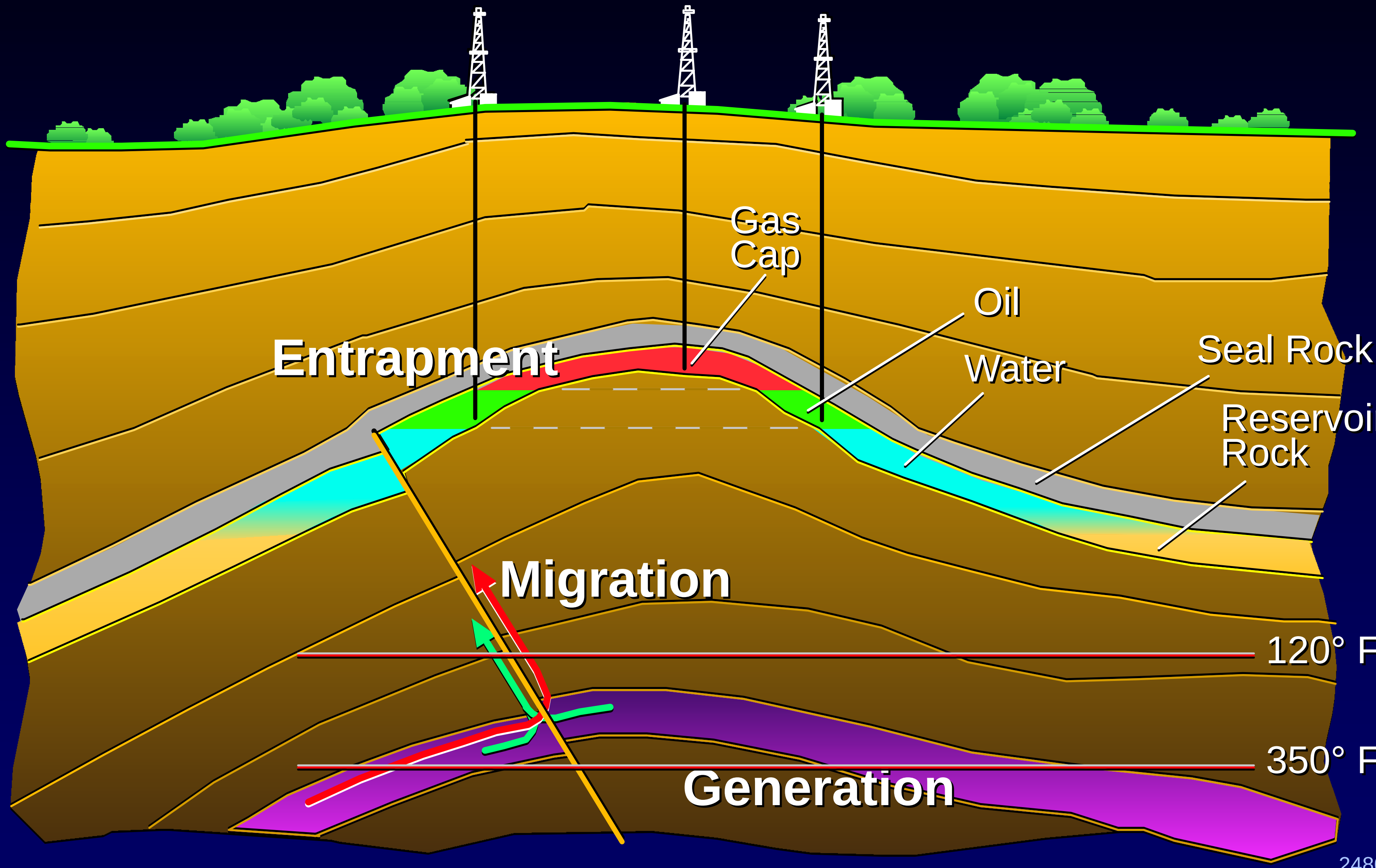
- **Seal Rock** - A rock through which oil and gas cannot move effectively (such as mudstone and claystone)

- **Migration Route** - Avenues in rock through which oil and gas moves from source rock to trap

- **Trap** - The structural and stratigraphic configuration that focuses oil and gas into an accumulation

Source: AAPG

Petroleum System Processes



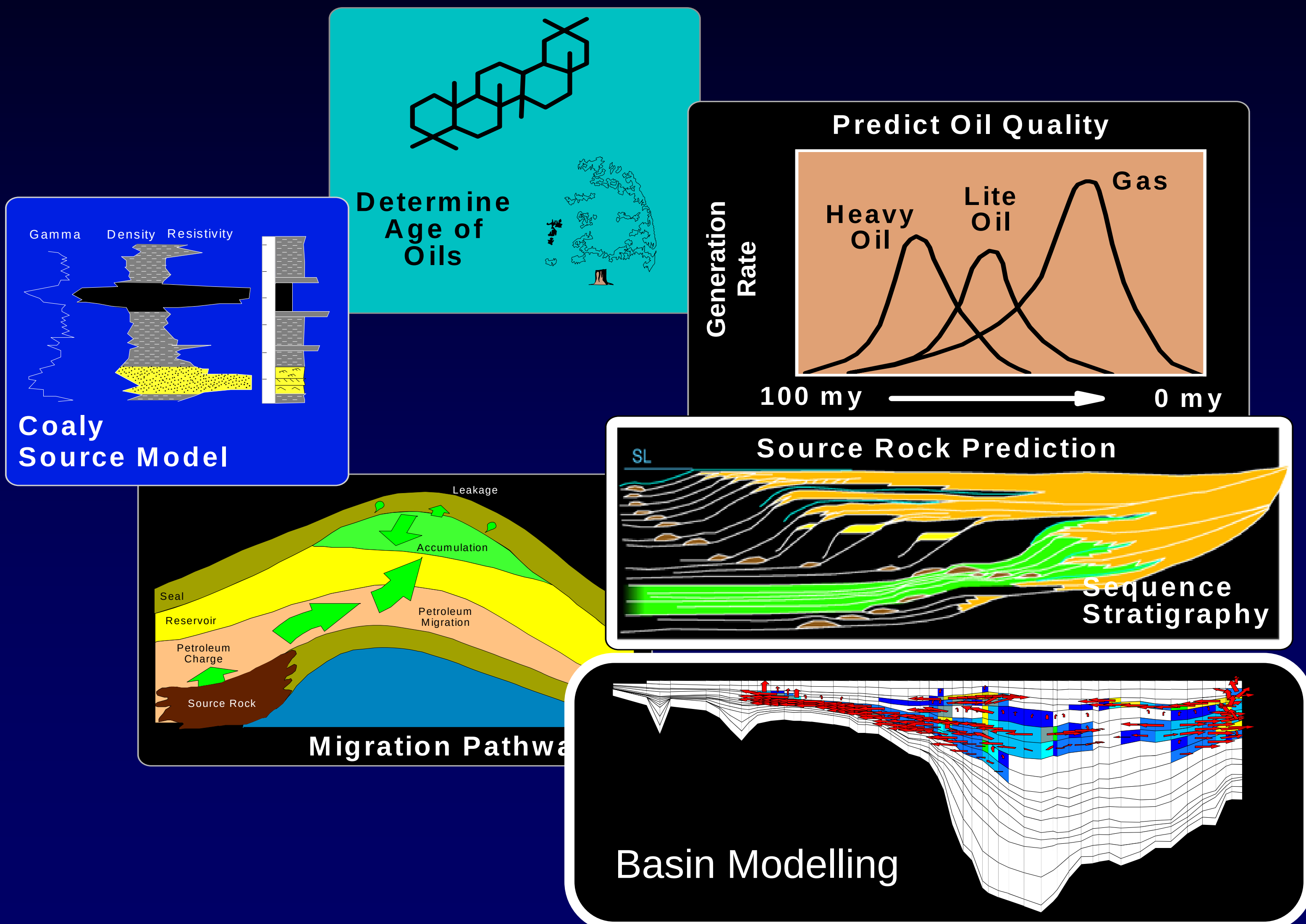
Source: AAPG

Petroleum System Processes

- **Generation** - **Burial of source rock to temperature and pressure regime sufficient to convert organic matter into hydrocarbon**
- **Migration** - **Movement of hydrocarbon out of the source rock toward and into a trap**
- **Accumulation** - **A volume of hydrocarbon migrating into a trap faster than the trap leaks resulting in an accumulation**
- **Preservation** - **Hydrocarbon remains in reservoir and is not altered by biodegradation or "water-washing"**
- **Timing** - **Trap forms before and during hydrocarbon migrating**

Source: AAPG

Basin modelling is an interpretation tool for understanding the petroleum system.



Basin Modelling

Integrating geology, physics and geochemistry to simulate:

- Sediment burial and compaction : Terzaghi's and Darcy's laws
- Heat transfer : transient heat equation
- HCs generation : 1st order compositional kinetics
- HCs migration and entrapment : multi-phase Darcy's law

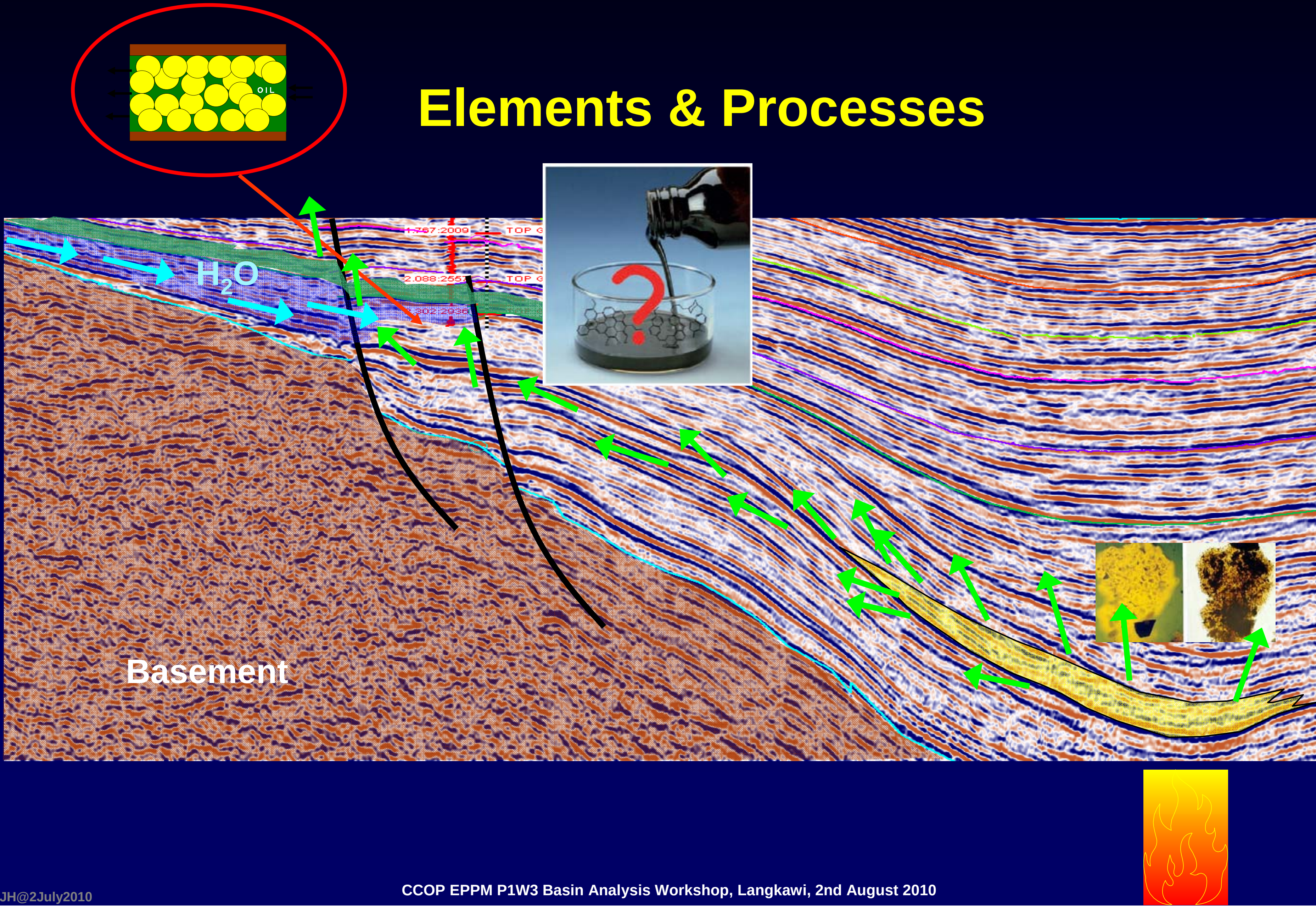
☞ Reconstruct pressure regimes and predict overpressure

☞ Delineate hydrocarbon migration pathways and identify structural and stratigraphic traps

☞ Assess the prospect value by estimating the quantity and predicting the quality of trapped hydrocarbons

Geologic Risk

Elements & Processes

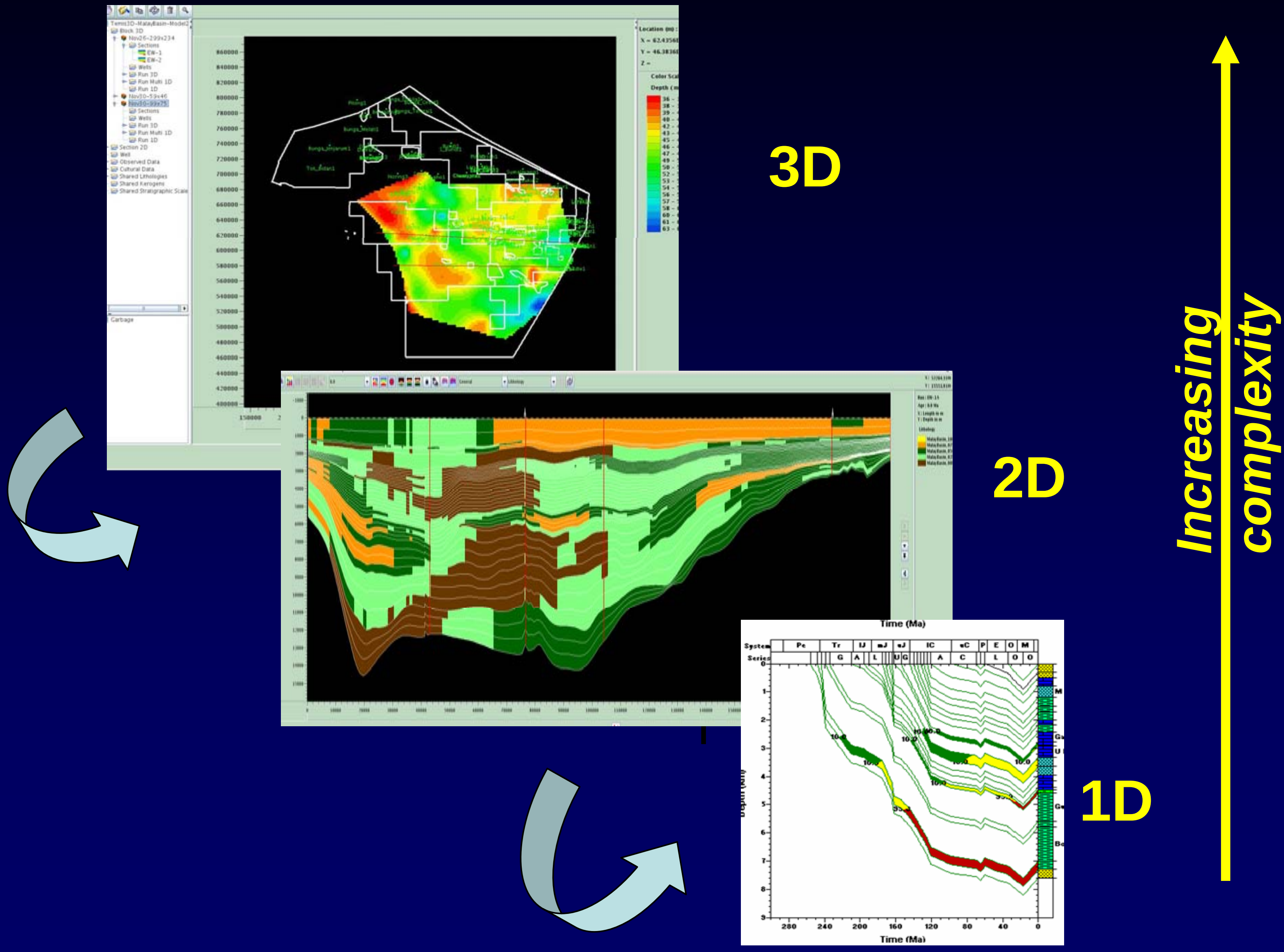


Objective of Basin Modelling

Basin modelling is used during petroleum exploration to predict the timing and extent of petroleum generation and the location of hydrocarbon accumulations.

RISK REDUCTION

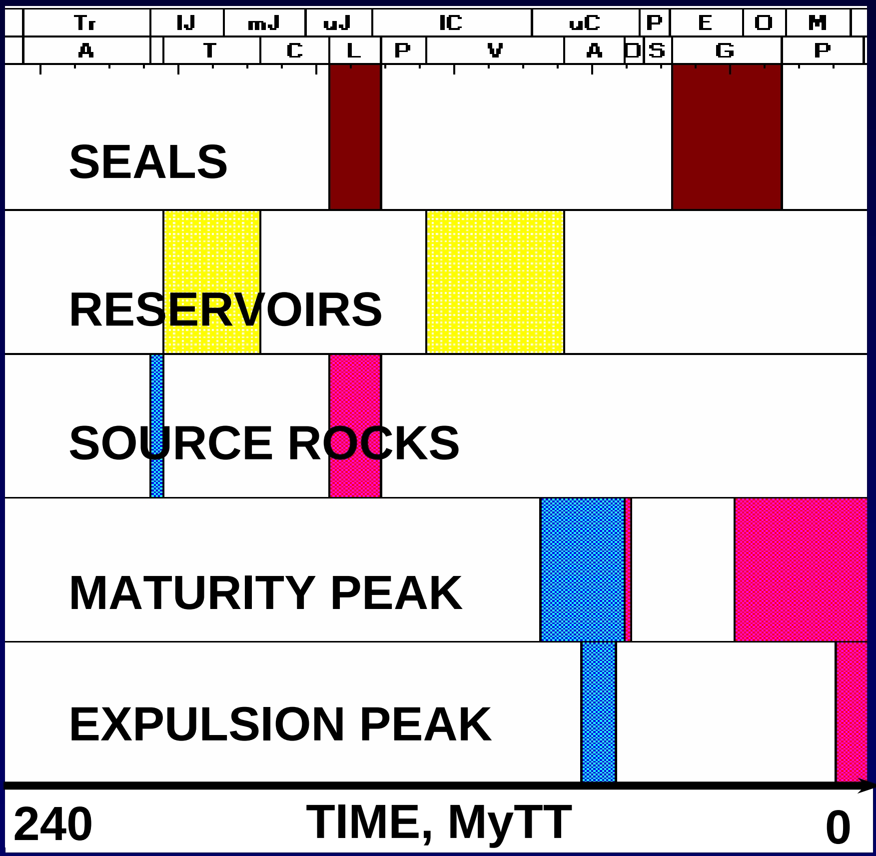
Types of Basin Modelling

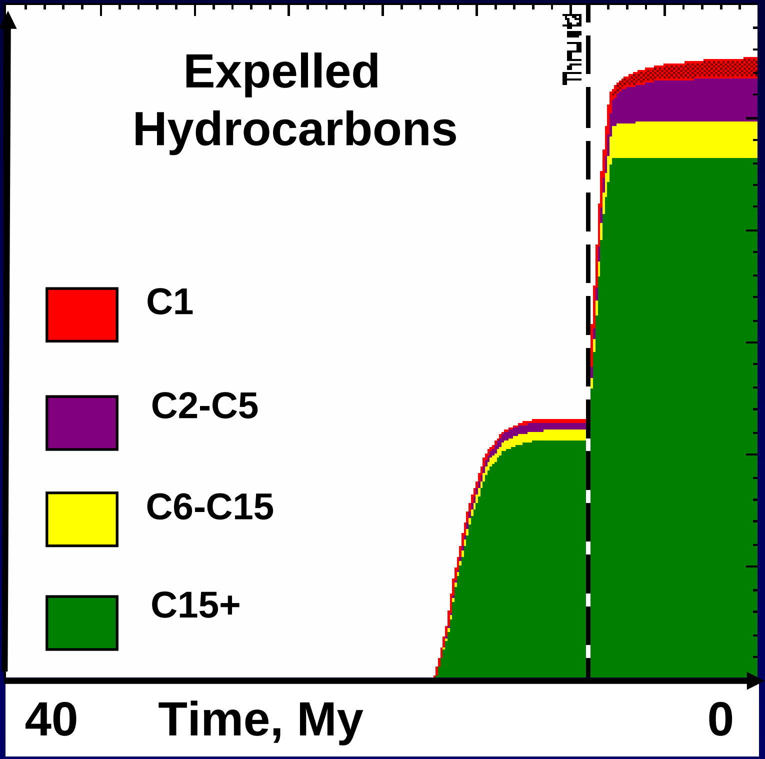


1D Basin Modelling

WHY 1D MODELING ?

TIMING OF GENERATION AND EXPULSION

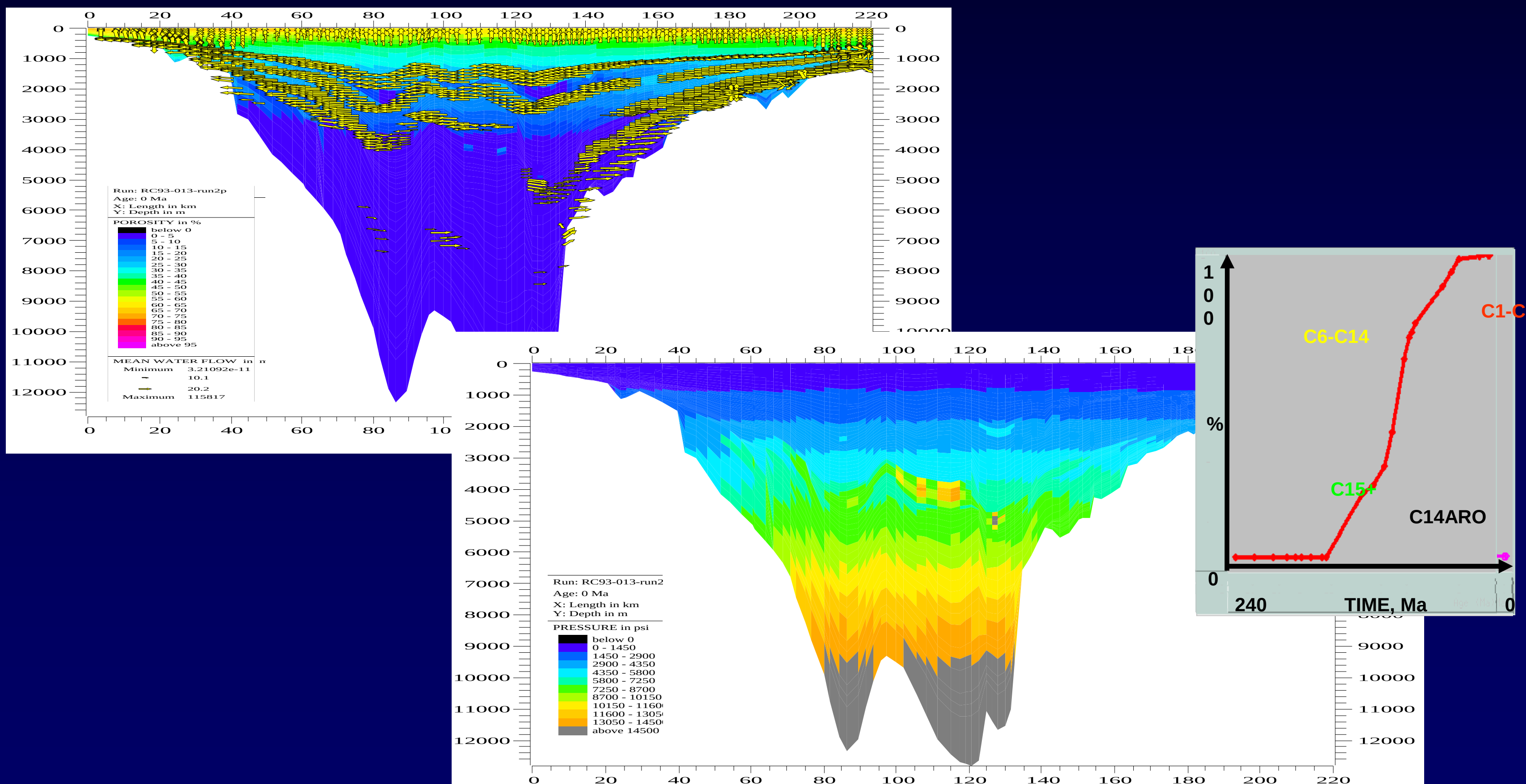




2D Basin Modelling

WHY 2D MODELING ?

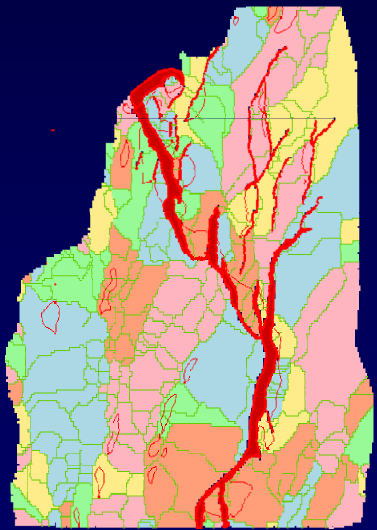
- PRESSURE FIELD AND MIGRATION PATHWAYS
- QUALITATIVE PREDICTION (GOR, °API)

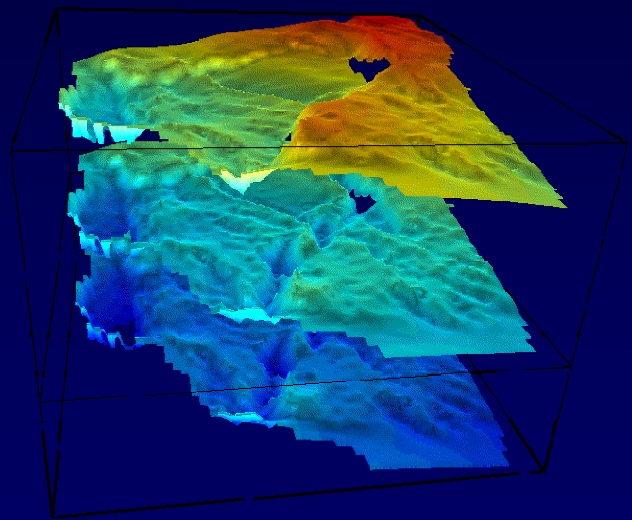


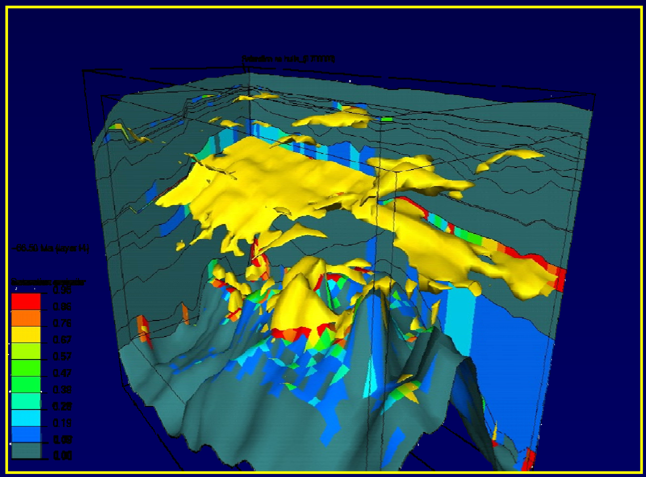
3D Basin Modelling

WHY DO 3D MODELING ?

- Drainage area and flow lines delineation
- Kitchen evaluation
- Quantitative Prospect Evaluation
- Prospect Ranking

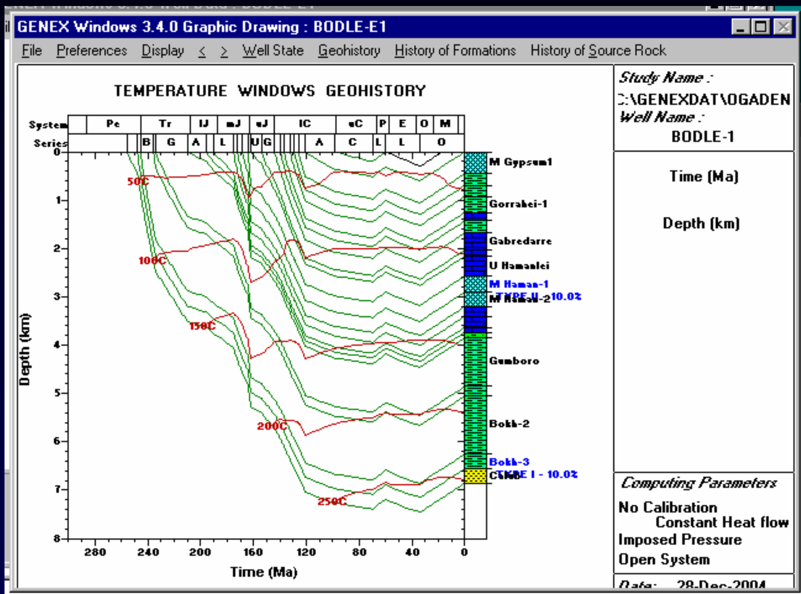


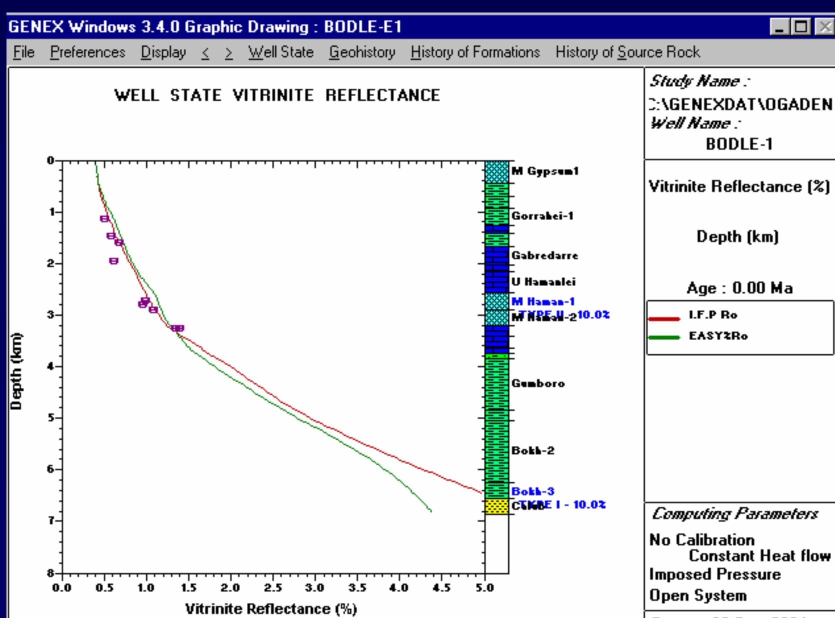




- RAPID PETROLEUM SYSTEM ANALYSIS
- FULL 3D SIMULATION

1D Basin Modelling – Data Input





GENEX Windows 3.4.0 Well Data : BODLE-E1

File Preferences Stratigraphy Thermal Data Geochemical Measurements

Formations and Source Rocks Reference Datum : BURIAL

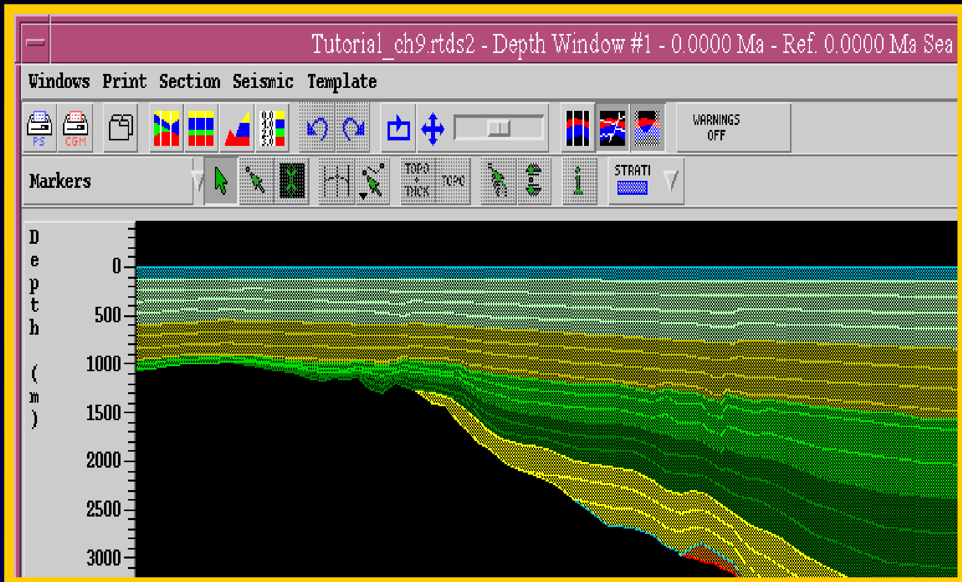
	Type U/M F	Formation Name	Age (Ma)	Depth (m)	Thickness Eroded Missing	Petro Physics Litho. / Meas.	Lithologies Composition (%) Measurements (Phi Law)	Paleo Bathy. (m)
1	U	Oligocene-P	34.00		-600.0			0.0
2	M	Late Plioce	60.00		300.0	Litho.	SANDSTONE:100	0.0
3	U	Late Maas-E	70.00		-200.0			100.0
4	M	Ceno-Early	99.00		200.0	Litho.	SANDSTONE:100	100.0
5	M	Aptian Albi	121.00		300.0	Litho.	LIMESTONE:100	100.0
6	F	M Gypsum1	126.00	456.0	456.0	Litho.	SAL:40 ANH:40 SHA:20	100.0
7	F	M Gypsum2	129.30	700.1	244.1	Litho.	SH:60 SA:20 AN:10 DO:10	100.0
8	F	M Gypsum3	132.00	925.1	225.0	Litho.	SHAL:80 ANHY:20	100.0
9	F	Gorrahei-1	136.70	1256.0	330.9	Litho.	SHAL:90 LIME:10	100.0
10	F	Gorrahei-2	139.70	1431.0	175.0	Litho.	LIM:80 SAN:10 SHA:10	100.0
11	F	Gorrahei-3	144.00	1681.0	250.0	Litho.	SHAL:80 SAND:20	100.0
12	F	Gabredarre	154.00	2035.0	354.0	Litho.	MARL:50 LIME:50	200.0
13	F	Uarandab	162.00	2163.0	128.0	Litho.	SHAL:50 LIME:50	300.0
14	F	U Hamanlei	164.00	2573.0	410.0	Litho.	LIME:70 MARL:30	200.0
15	F	M Haman-1	168.30	2905.0	332.0	Litho.	ANH:75 LIM:20 DOL:5	100.0
16	F	M Haman-2	172.20	3205.0	300.0	Litho.	LIME:50 ANHY:50	100.0
17	F	M Haman-3	175.00	3405.0	200.0	Litho.	LIME:95 ANHY:5	100.0
18	F	L Hamanlei	190.00	3633.0	228.0	Litho.	LIM:70 SIL:15 SHA:15	100.0
19	F	Transition	196.00	3734.0	101.0	Litho.	LIM:60 SHA:30 MAR:10	100.0

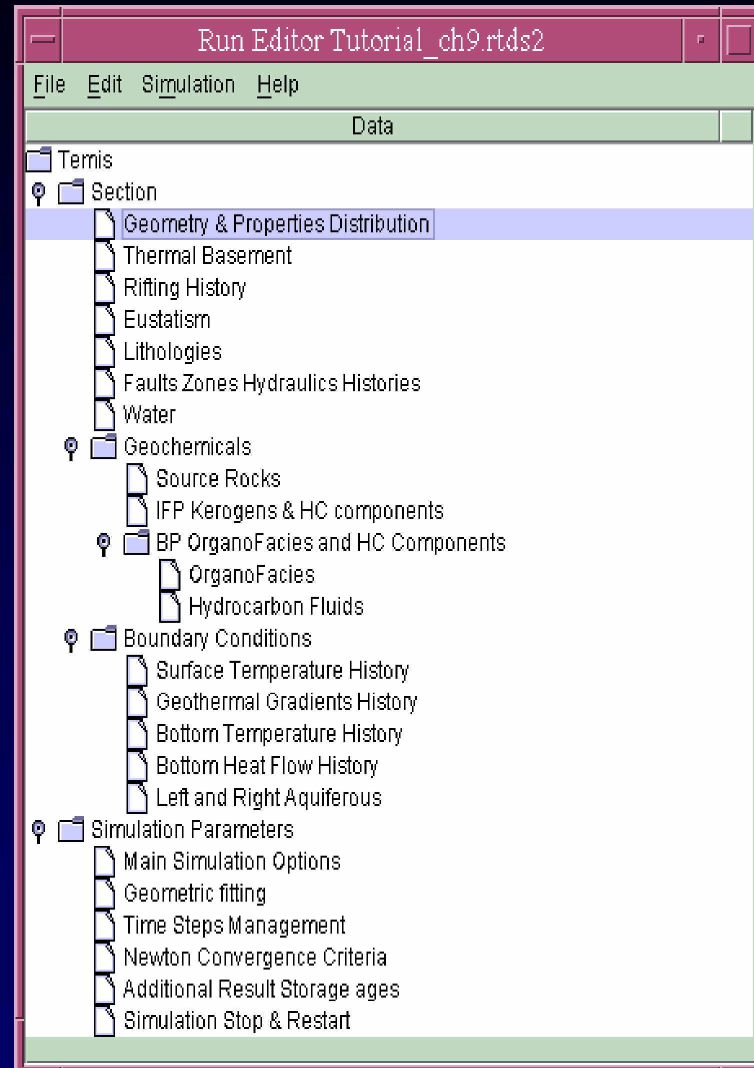
Ins. Line Del. Line Exit

- Stratigraphy
- Lithofacies
- Thermal
- Source Rocks

TIMING OF GENERATION AND EXPULSION

2D Basin Modelling – Data Input

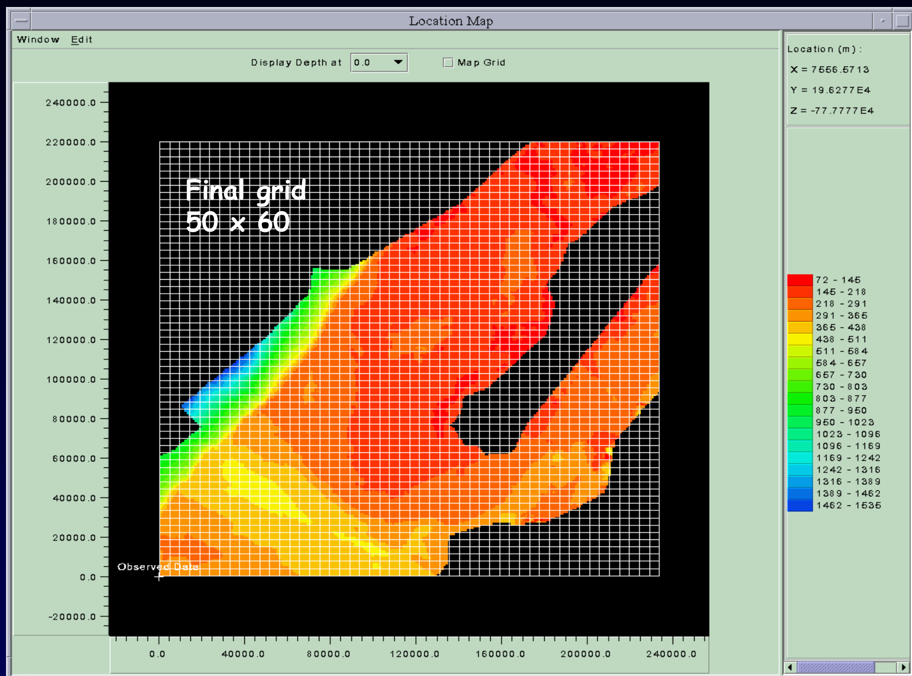


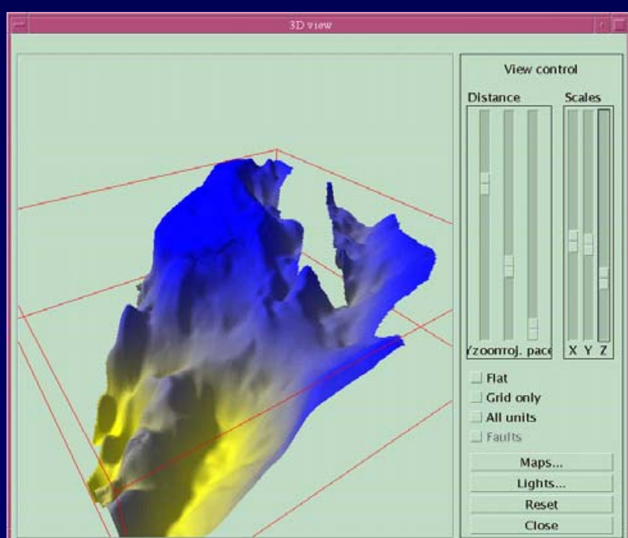


- •Cross-section
- •Stratigraphy
- •Lithofacies
- •Thermal
- •Source Rocks

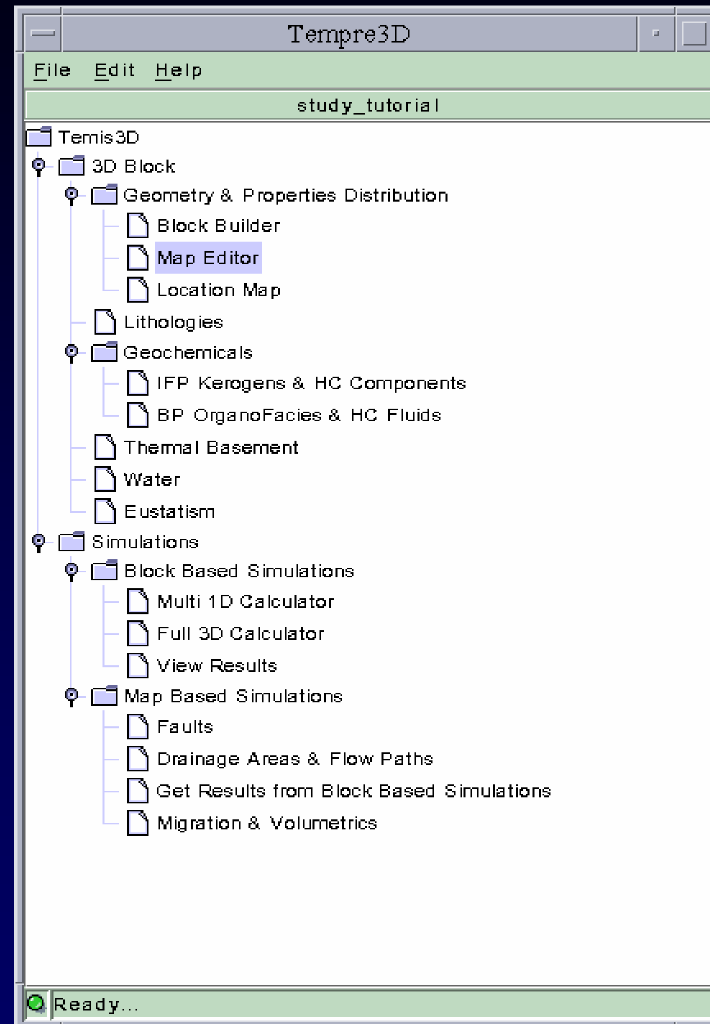
PRESSURE PREDICTION AND MIGRATION PATHWAYS

3D Basin Modelling – Data Input





•Maps
•Stratigraphy
•Lithofacies
•Thermal
•Source Rocks



DRAINAGE PATTERN
QUANTITATIVE PROSPECT EVALUATION

Hydrocarbon Generation

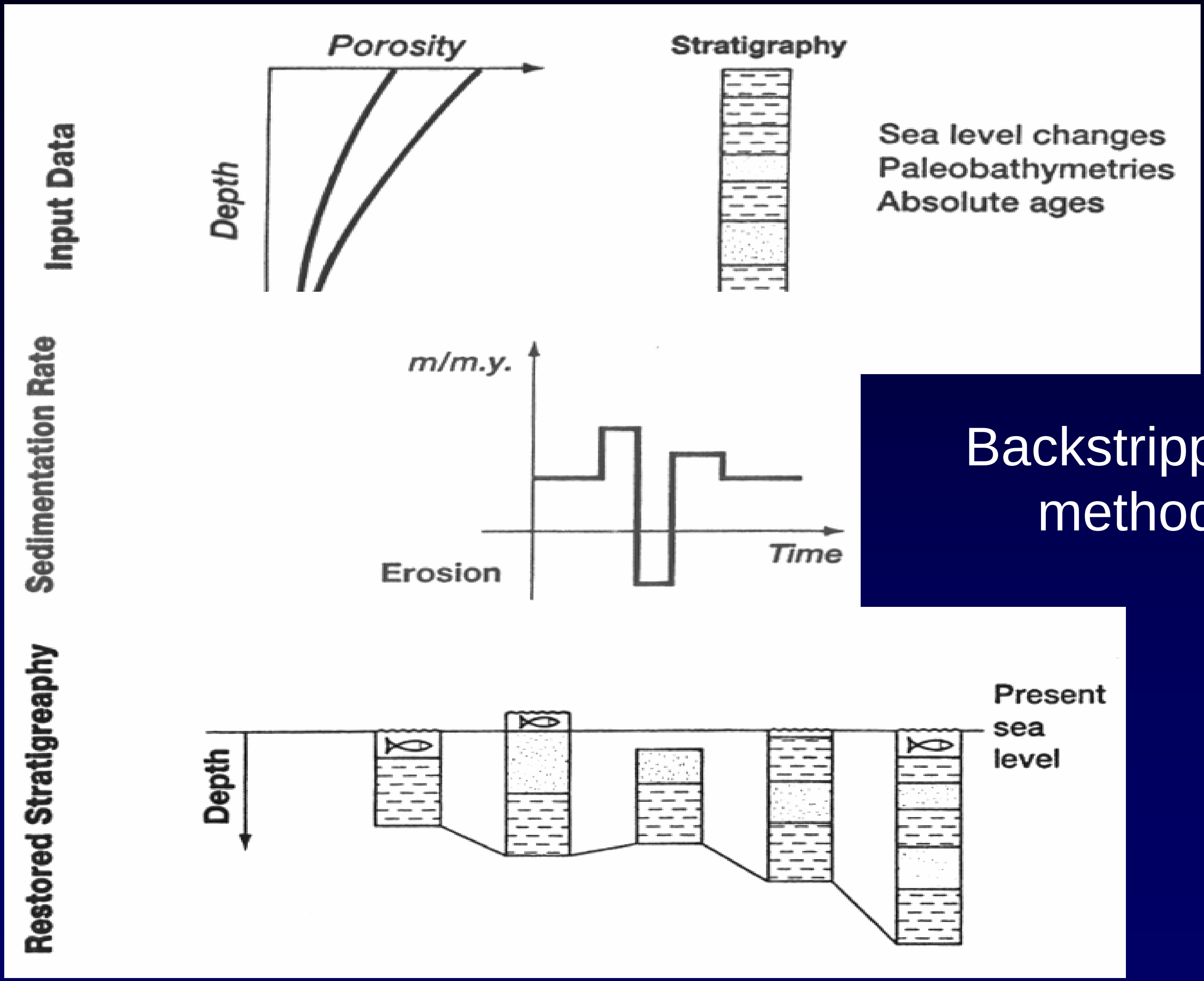
↑

Maturity modelling

↑

Depends on Cooking TIME and TEMPERATURE

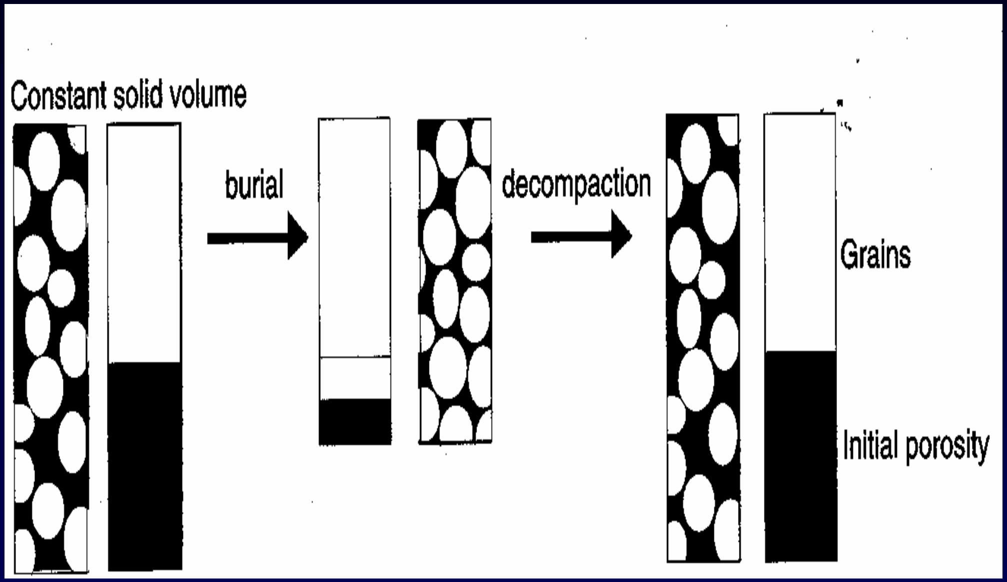
Backstripping/Decompaction



Backstripping method

Forward modeling

BACKSTRIPPING/DECOMPACTION

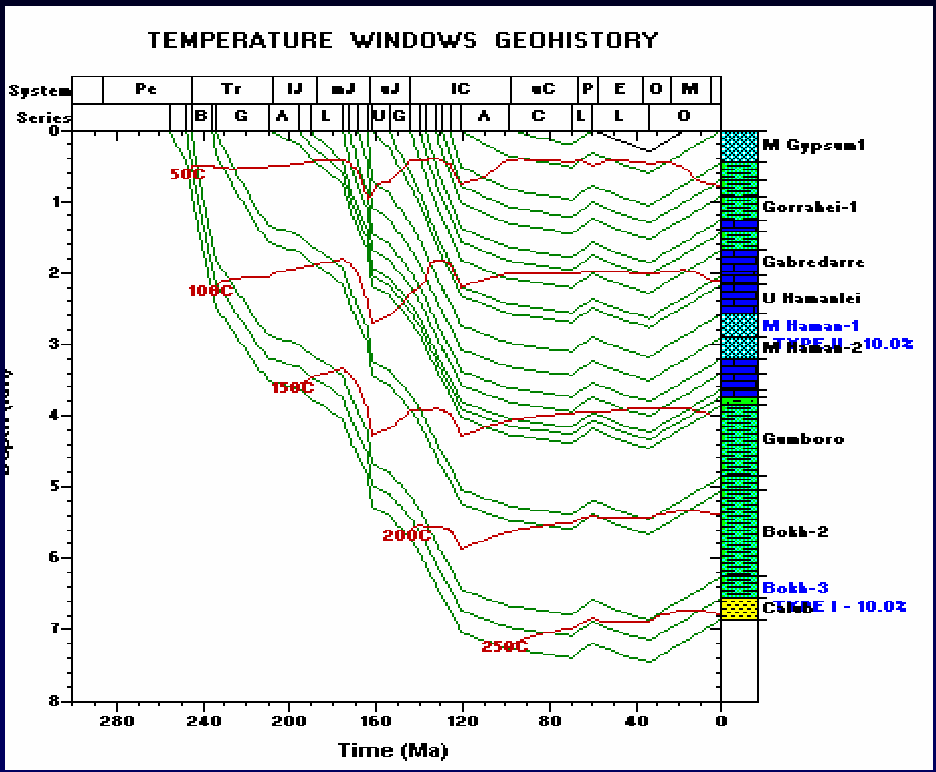


Giles et al., 1998

- **Process of thickness reconstruction through sequential removal of top sedimentary layer**

- **Assume the amount of solid matrix remains constant, while rock volume is changed with depth of burial due to the loss of porosity.**

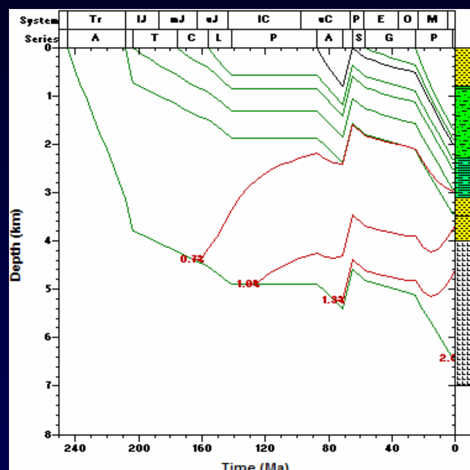
GEOHISTORY/BURIAL HISTORY

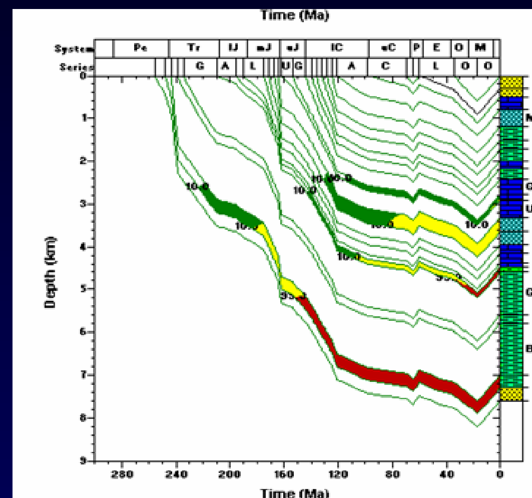


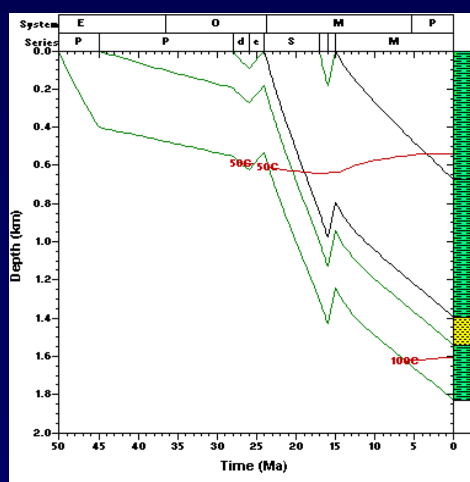
- To determine depositional, thermal & maturity histories
- Reconstruct by backstripping or decompaction, based on porosity-depth relationship

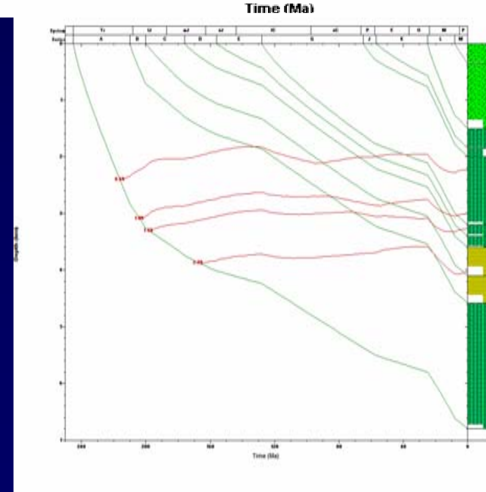
1. Time of uplift ?
2. Which thickness is eroded ?
3. When do rapid subsidence occur ?
4. What is the subsidence rate ?

The Time Temperature Index

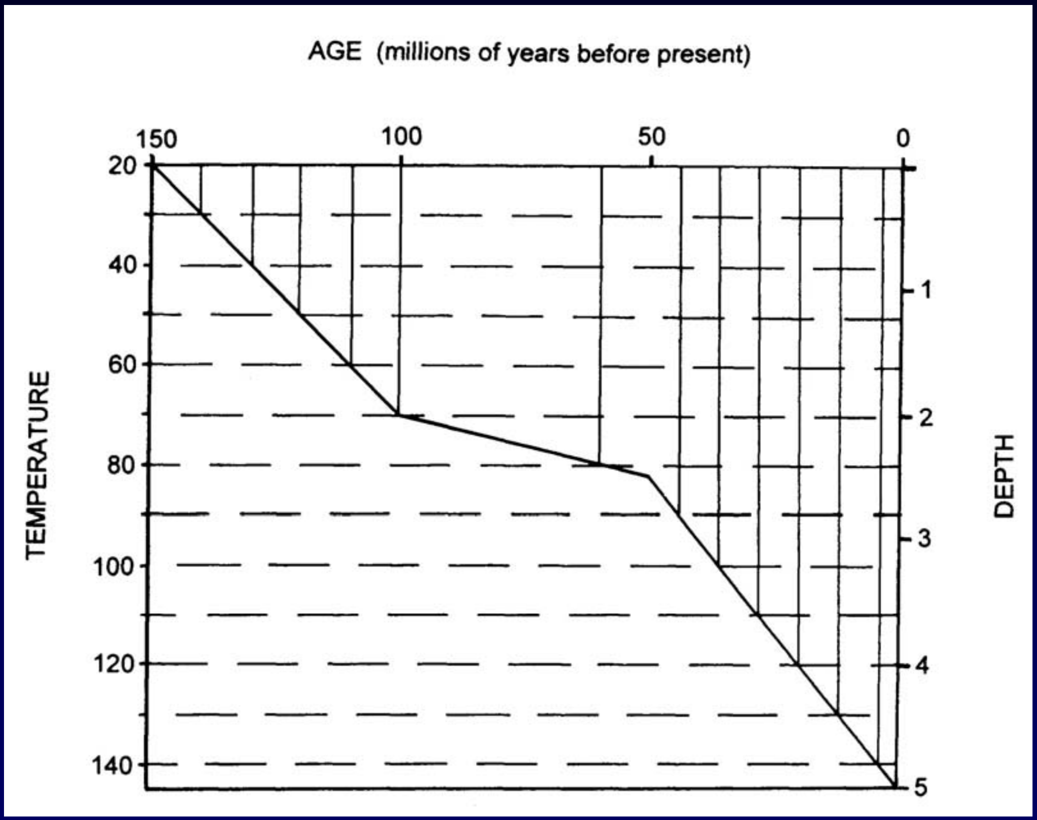








Lopatin TTI Maturity Model

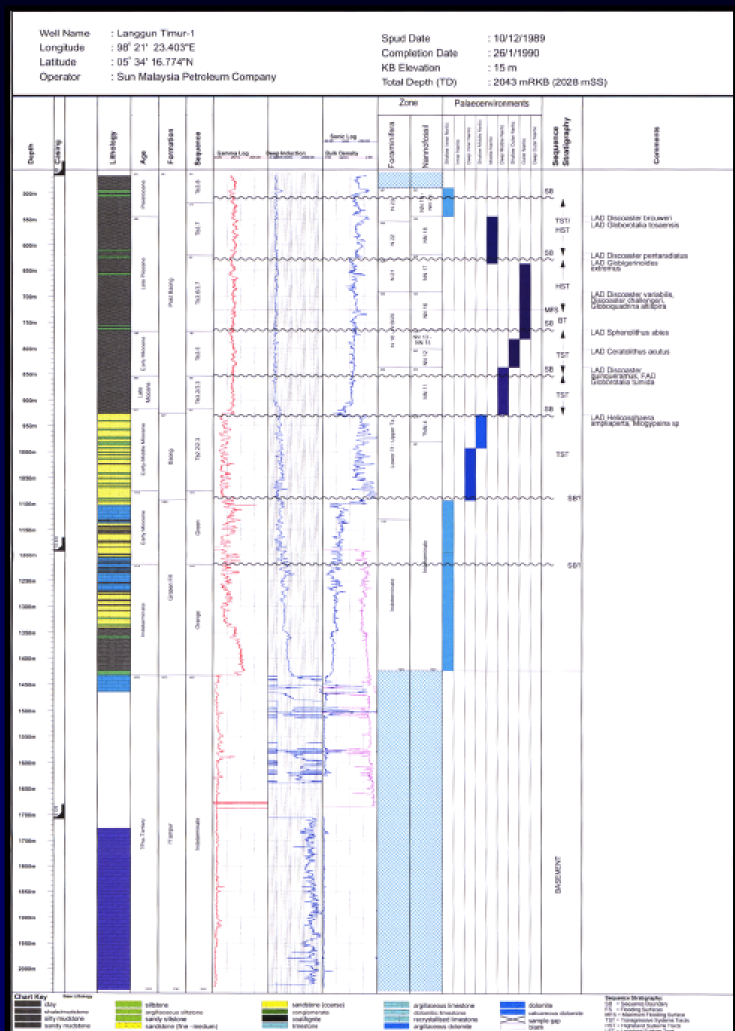


Steps:

- Construct burial history curves
- Superimpose temperature history
- Assign t & T factors to each interval
  t-factor (Time) is length of time (m.y) spent in the interval
  T-factor (Temperature) assumes rate of reaction double with an increase (10^{o}C) in temperature
- Calculate interval TTI by multiplying t-factor x T-factor
- Add up all interval TTI to get Total TTI

Barker, 1996

Stratigraphy



Formation	Bottom Depth (m)	Age (my)	Thickness (m)
PB-nn21	592	2	592
PB-nn18	619	2.4	27
PB-nn17	692	3.4	73
PB-nn15	802	4.5	110
PB-nn12	834	5.5	32
PB-nn11	927	16.2	93
BG-nn4	1093	22	166
BM-nn3	1434	49	341
TC	2043	65	609

Steps:

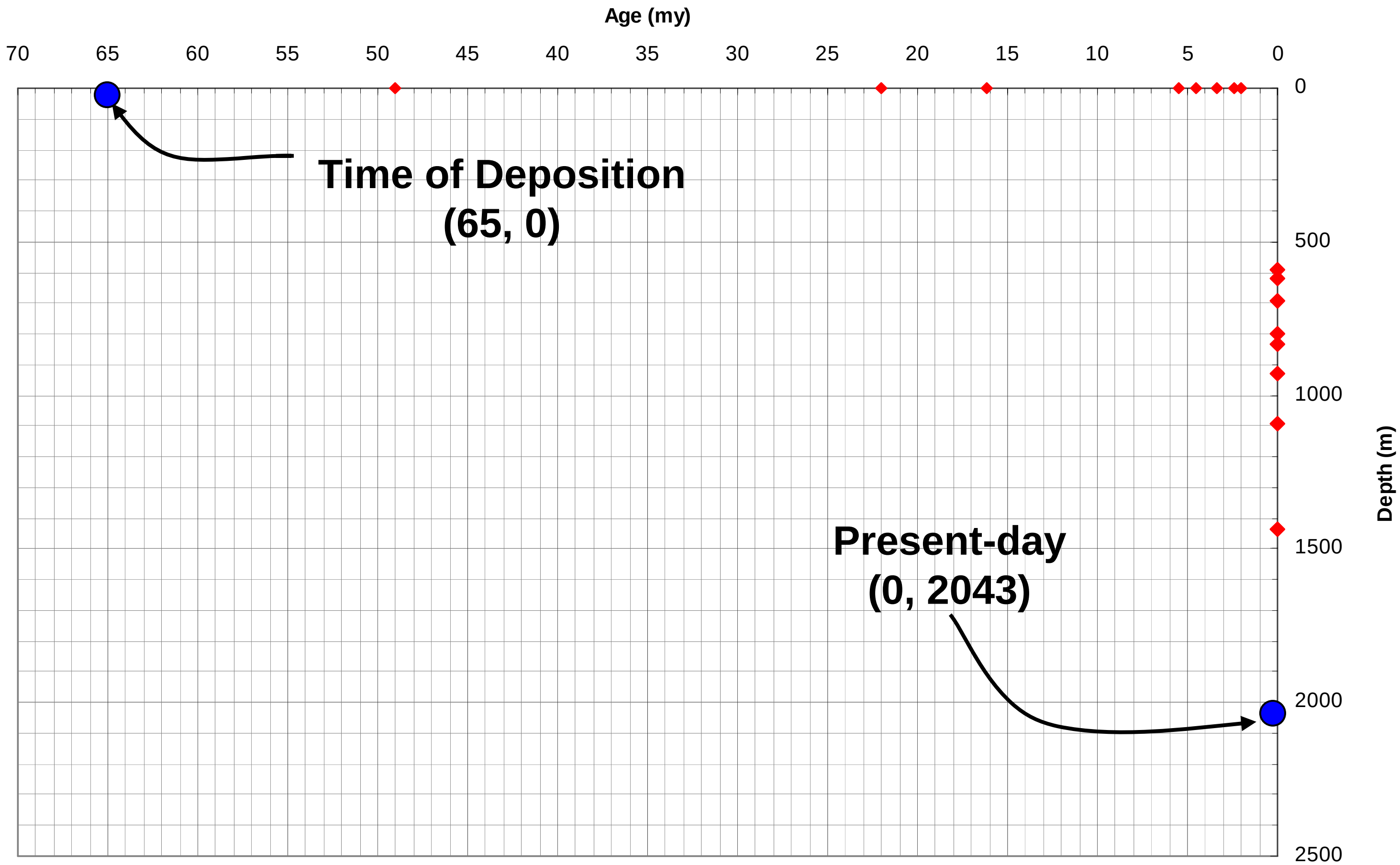
- Begin by reconstructing the depositional and tectonic history of the sedimentary layer .
- Best done by plotting bburial depth against Age.
- Plot present-day temperature profile & extrapolate into the past.
- Calculate time spent in the temperature intervals.
- Compute interval TTI by multiplying time spent and temperature factor (t-factor x T-factor).
- Summed all up to give TTI maturity.

Note: These are NOT cross-sections

- **Use time stratigraphy data for constructing burial history curve.**
- **Locate starting & end points**
- **Identify the events (time) and amount of burial (thickness)**

Burial History Curve for TC

Events	Time (my)	Depth
Present-day	0	2043
TC	65	0



- Identify the events (time) and amount of burial (thickness)
- Plot the time-depth coordinates

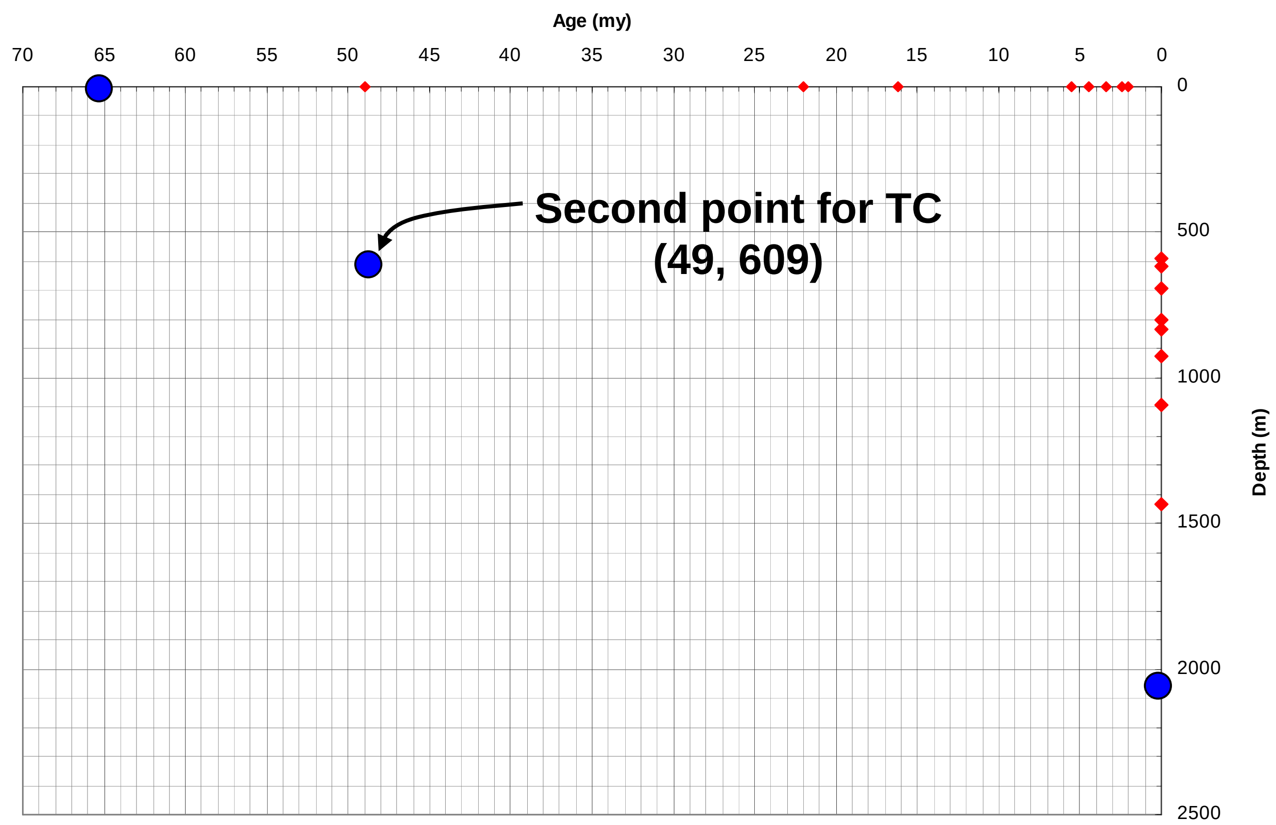
Burial History Curve for TC

Events	Time (my)	Depth
Present-day	0	2043
PB-nn21	2	
PB-nn18	2.4	
PB-nn17	3.4	
PB-nn15	4.5	
PB-nn12	5.5	
PB-nn11	16.2	
BG-nn4	22	
BM-nn3	49	
TC	65	0

• Plot second position for Formation TC in time & depth

Burial History Curve for TC

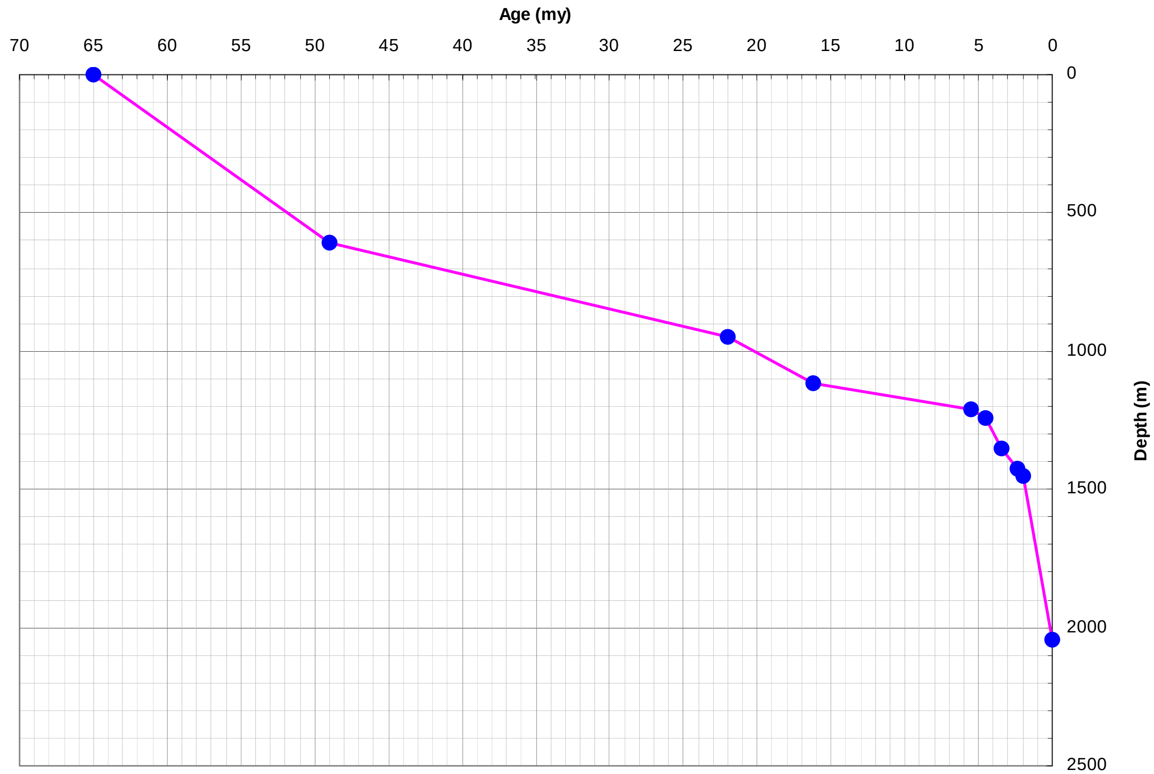
Events	Time (my)	Depth	Calculation
Present-day	0	2043	
PB-nn21	2		
PB-nn18	2.4		
PB-nn17	3.4		
PB-nn15	4.5		
PB-nn12	5.5		
PB-nn11	16.2		
BG-nn4	22		
BM-nn3	49	609	= 609 (i.e thickness of TC
TC	65	0	0



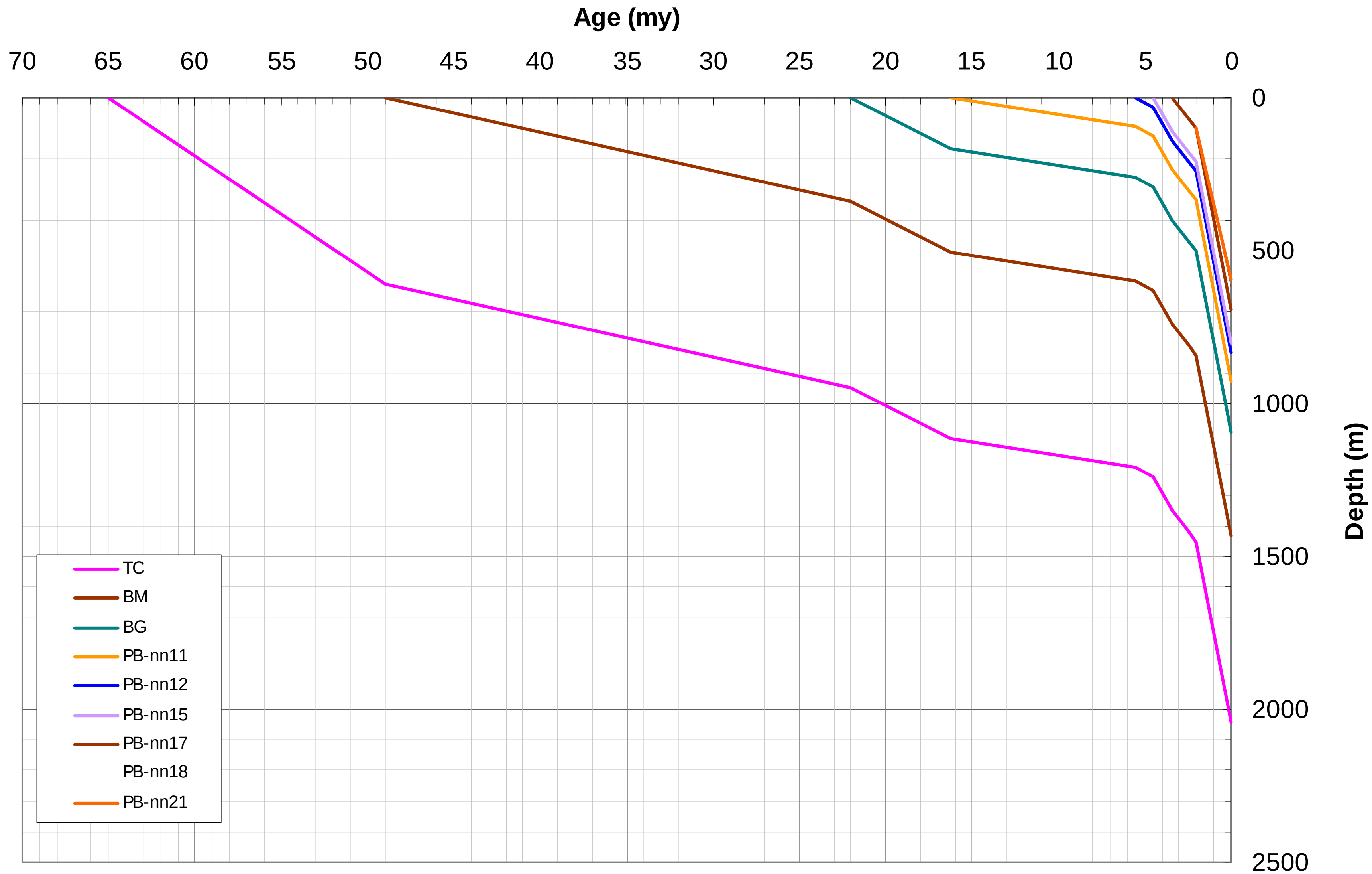
• Complete burial history for Formation TC

Burial History Curve for TC

Events	Time (my)	Depth	Calculation
Present-day	0	2043	= 609+341+166+93+32+110+73+27+592
PB-nn21	2	1451	= 609+341+166+93+32+110+73+27
PB-nn18	2.4	1424	= 609+341+166+93+32+110+73
PB-nn17	3.4	1351	= 609+341+166+93+32+110
PB-nn15	4.5	1241	= 609+341+166+93+32
PB-nn12	5.5	1209	= 609+341+166+93
PB-nn11	16.2	1116	= 609+341+166
BG-nn4	22	950	= 609+341
BM-nn3	49	609	= 609 (i.e thickness of TC
TC	65	0	0



Burial History Curves for Langgun Timur-1



BASIN MODELLING

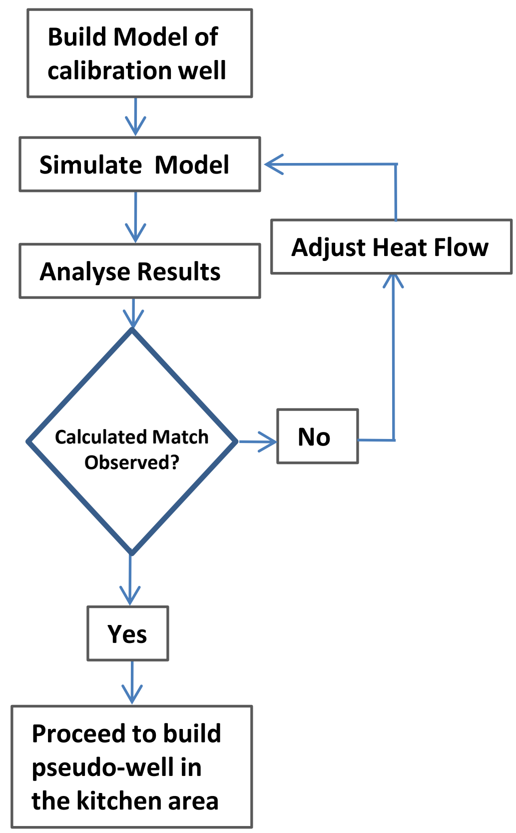
Learning Outcomes

1. **To build a 1D model that captures the main elements and processes of the petroleum system to allow the assessment of source rock maturity and the timing of hydrocarbon generation.**

2. **To build a simple source rock maturity map using results from the 1D modelling.**

3. **T o assess potential migration pathways and evaluate whether a specific can be charged, or not.**

STEPS



1. **Data Collection**

2. **Construct 1D model of calibration well**

3. **Incorporate thermal model by defining the boundary conditions**

4. **Run model**

5. **Compare calculated results with the observed data (calibration)**

6. **Adjust basal heat flow values until a satisfactory match is obtained. This heat flow value is assumed to represent the regional basal heat flow and thus can be applied to the kitchen area.**

7. **Build the 1D model of a pseudo-well in the kitchen area. Apply the deduced heat flow value.**

8. **Incorporate appropriate source rock properties (TOC, HI, kerogen kinetics)**

9. **Run kitchen area pseudo-well model. Use the results to determine the depth to the top of the oil window and the timing of hydrocarbon generation.**

10. **Transfer the depth to oil window on to the source rock map and color in the mature source pod.**

11. **Overlay the reservoir map onto the source rock map (assuming vertical migration).**

12. **Trace the potential migration pathways. Can the prospect be charged?**

WELL STRATIGRAPHY

Table 1.

	LANGGUN TIMUR-1									
	LAYER		TOP (m)	BASE (m)	ERODED (m)	DEPO FROM (Ma)	DEPO TO (Ma)	ERODED FROM (Ma)	ERODED TO (Ma)	LITHOLOGY
Pleistocene	PB-nn21		0	592		2	0			Sh
Pliocene	PB-nn18		592	619		2.4	2			Sh
	PB-nn17		619	692		3.4	2.4			Slst
	PB-nn 15		692	802		4.5	3.4			Sst
	PB-nn12		802	834		5.5	4.5			Sh
U. Miocene	PB-nn11	UC2	834	927		10	5.5			Sh
L. Miocene	BG-nn4		927	1093	457	22	16.2	16.2	10	Sst
	BM-nn3	UC1	1093	1434		25	22			Lst
Pre-Tert.	TC		1434	2042	305	65	49	49	25	Dolomite

Table 2.

	SINGA BESAR-1								
	LAYER	TOP (m)	BASE (m)	ERODED (m)	DEPO FROM (Ma)	DEPO TO (Ma)	ERODED FROM (Ma)	ERODED TO (Ma)	LITHOLOGY
Pleistocene	PB-nn21	0	485		2	0			Slst
Pliocene	PB-nn18	485	558		2.4	2			Sh
	PB-nn17	558	704		3.4	2.4			Sh
	PB-nn15	704	722		4.8	3.4			Sh
	PB-nn12	722	768		5.5	4.8			Sh
U. Miocene	PB-nn11	768	783		10	5.5			Sh
Pre-Tert.	TC	783	860	180	65	22	22	10	Lst
							65		

Table 3.

MATURITY WINDOWS

	(%Ro)	Depth (m)	Depth (nearest contours)
Immature	0.25		
Early Oil	0.55		
main Oil	0.7		
Late Oil	1		
Wet Gas	1.3		
Dry Gas	2		
Overmature	> 4.0		

Langgun Timur-1
X 428738m Y 615812m
KB 15m
WD 95m
TD 2042m

Singa Besar-1
X 407013m Y 650734m
KB 16m
WD 110m
TD 806m

DAA@2July2010

CALIBRATION DATA

Table 4.

LANGGUN TIMUR-1			
DEPTH (m)	Min Vro (%)	Max Vro (%)	Mean Vro (%)
921	0.25	0.37	0.3
1003	0.25	0.39	0.31
1113	0.25	0.37	0.28
1132	0.25	0.36	0.31
1184	0.25	0.39	0.31
1195	0.25	0.36	0.3
1305	0.3	0.42	0.36
1341			1.09
1392	1.08	1.18	1.11
1414	1.22	1.58	1.44
1428	1.07	1.2	1.15

Table 5.

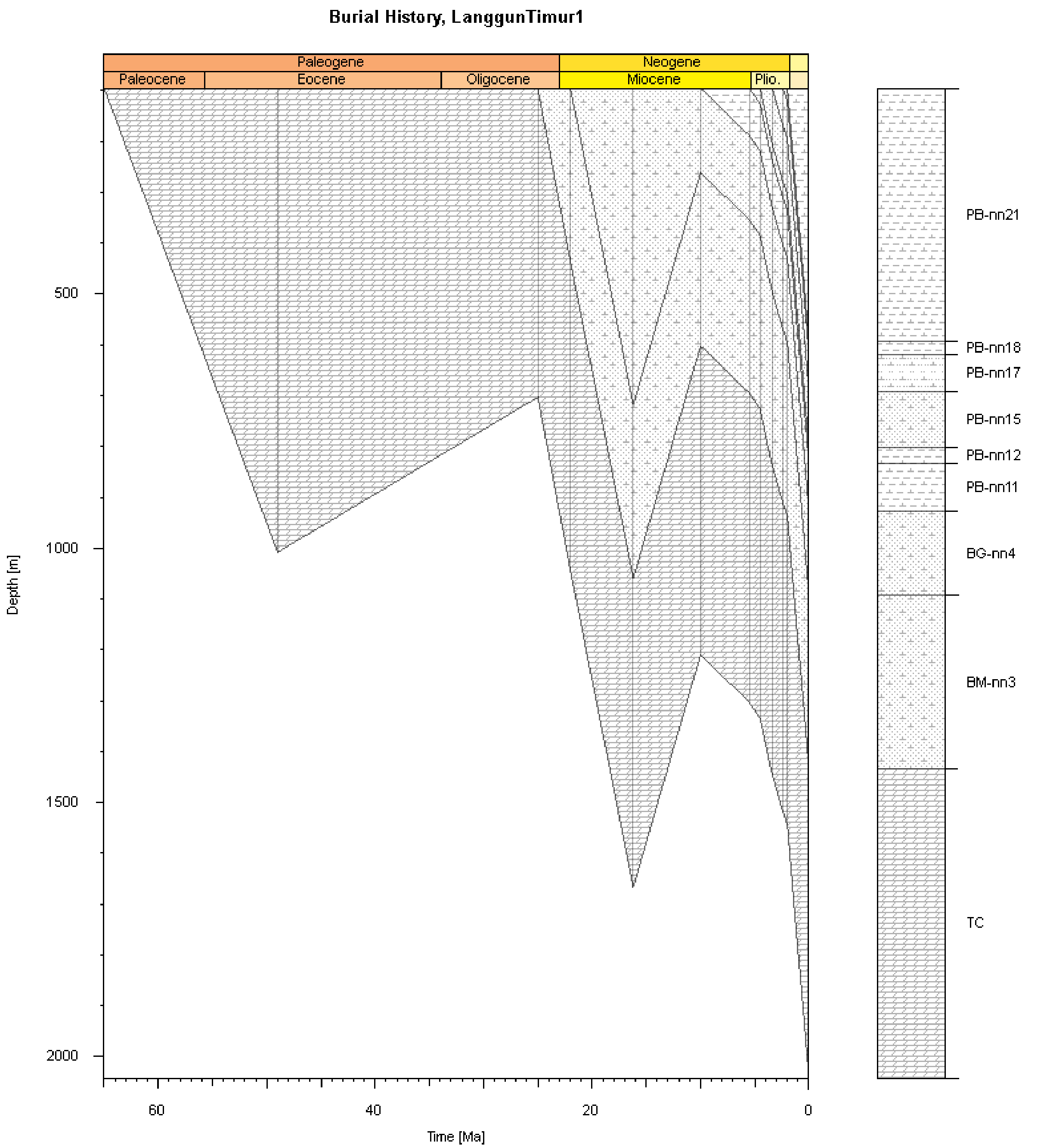
DEPTH (m)	Temp (Celsius)	Corrected
1430	82	100
2036	102	120

Table 6.

SINGA BESAR-1			
DEPTH (m)	Min Vro (%)	Max Vro (%)	Mean Vro (%)
631	0.25	0.39	0.31
686	0.25	0.35	0.29
741	0.25	0.42	0.34

Table 7.

DEPTH (m)	Temp (Celsius)
732	66*
	(*DST)



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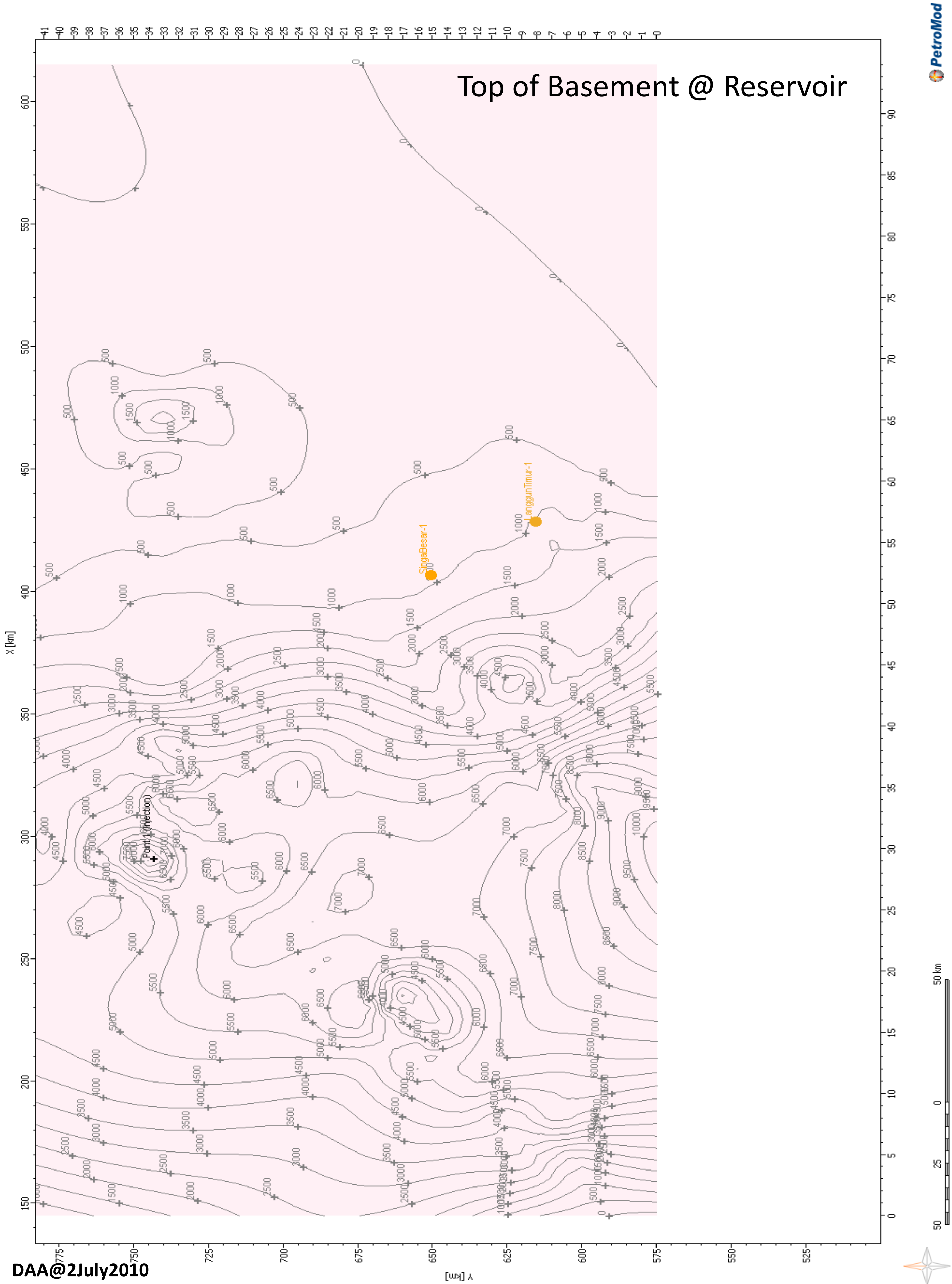
Top of Basement @ Reservoir



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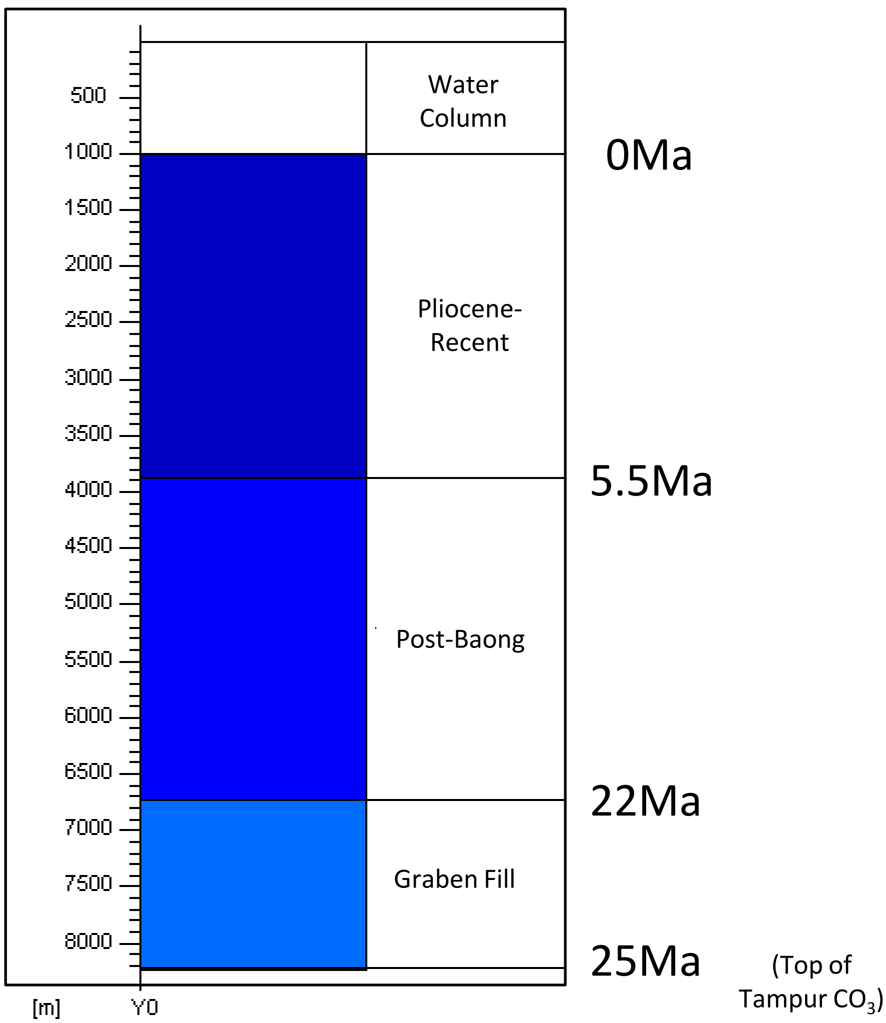
Pseudo-well from the Kitchen Area



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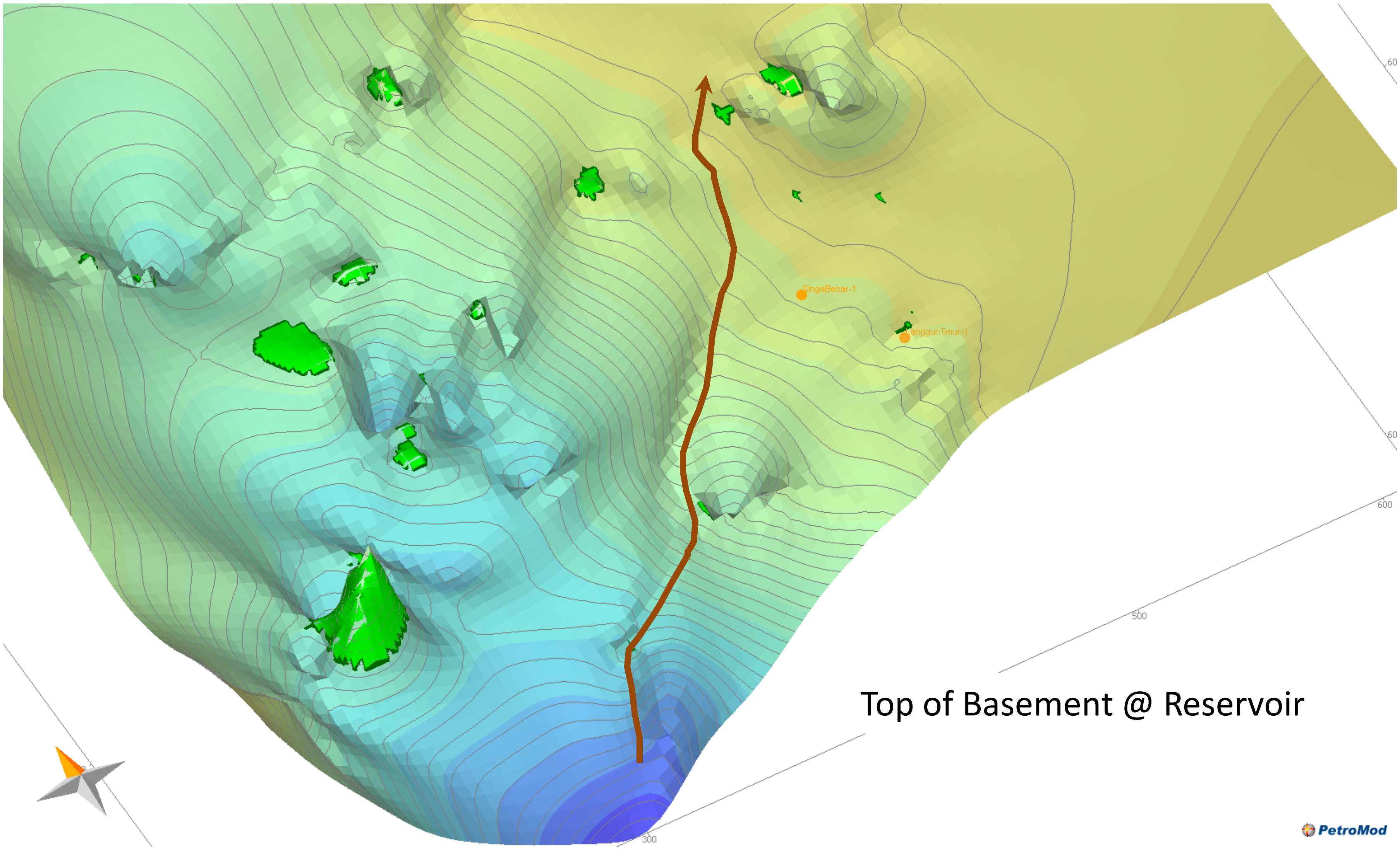
DAA@2July2010

Potential Migration Pathway from the Modeled Kitchen Area



Top of Basement @ Reservoir

The temperature interval

- Lopatin chose the 100 – 110 temp interval as the base interval and assigned it an index value n=0
- He then assigned other intervals the index values on the basis of:

$$n = (T_i-100)/10$$

- detailed in the following table

Temperature interval (°C)	*n*
30-40	-7
40-50	-6
50-60	-5
60-70	-4
70-80	-3
80-90	-2
90-100	-1
100-110	0
110-120	1
120-130	2
130-140	3
140-150	4
150-160	5
160-170	*m*

Temperature intervals

Lopatin then defined a Temperature Factor (γ)

- Rate of maturation increases by a factor of 2 for each 10°C interval so within any interval T_i-T_{i-1}:

$$\gamma = 2^n$$

Temperature interval (°C)	***n***	**γ**
30-40	-7	$2^{-7} = 0.0078$
40-50	-6	$2^{-6} = 0.0156$
50-60	-5	$2^{-5} = 0.0313$
60-70	-4	$2^{-4} = 0.0625$
70-80	-3	$2^{-3} = 0.125$
80-90	-2	$2^{-2} = 0.25$
90-100	-1	$2^{-1} = 0.5$
100-110	0	$2^{0} = 1$
110-120	1	$2^{1} = 2$
120-130	2	$2^{2} = 4$
130-140	3	$2^{3} = 8$
140-150	4	$2^{4} = 16$
150-160	5	$2^{5} = 32$
160-170	*m*	2^{m}

Temperature factors for different temperature intervals

Temperature-factor

time-factor

TTI Calculations

Temp. interval	n	γ =2n	Age (Ma)	Time spent in temperature interval (My)	Interval TTI	Cumulative TTI
			Formation A			
20-30	-8	0.00390625				
30-40	-7	0.0078125				
40-50	-6	0.015625				
50-60	-5	0.03125				
60-70	-4	0.0625				
70-80	-3	0.125				
80-90	-2	0.25				
90-100	-1	0.5				
100-110	0	1				
110-120	1	2				
120-130	2	4				
130-140	3	8	X		=	
140-150	4	16				
150-160	5	32				
160-170	6	64				
170-180	7	128				
180-190	8	256				
190-200	9	512				
200-210	10	1024				
210-220	11	2048				
220-230	12	4096				
230-240	13	8192				
240-250	14	16384				
250-260	15	32768				
260-270	16	65536				
270-280	17	131072				
280-290	18	262144				
290-300	19	524288				
300-310	20	1048576				
310-320	21	2097152				
320-330	22	4194304				

The time interval

- For his time interval, Lopatin selected the *time spent by the sediment in each temperature interval*
- The maturity added in any temperature interval I is given by:

$$\mathrm{Maturity}_i = 2^{n_i} \Delta T$$

Now, since maturation is cumulative

- The total maturity a sediment achieves passing through all time intervals in its burial history is given by the Time Temperature Index:

$$TTI = \sum_{n_{\min}}^{n_{\max}} 2^{n} \, \Delta T_{n}$$

Stage	TTI	Ro	TAI
Onset of oil generation	15	0.65	2.56
Peak oil generation	75	1.00	2.9
End of oil generation	160	1.30	3.2
Upper TTI limit for occurrence of API 40° oil	500	1.75	3.6
Upper TTI limit for occurrence of 50° API oil	1000	2.0	3.7
Upper TTI limit for wet gas	1500	2.2	3.75
Upper TTI limit for dry gas (methane)	65000	-	-

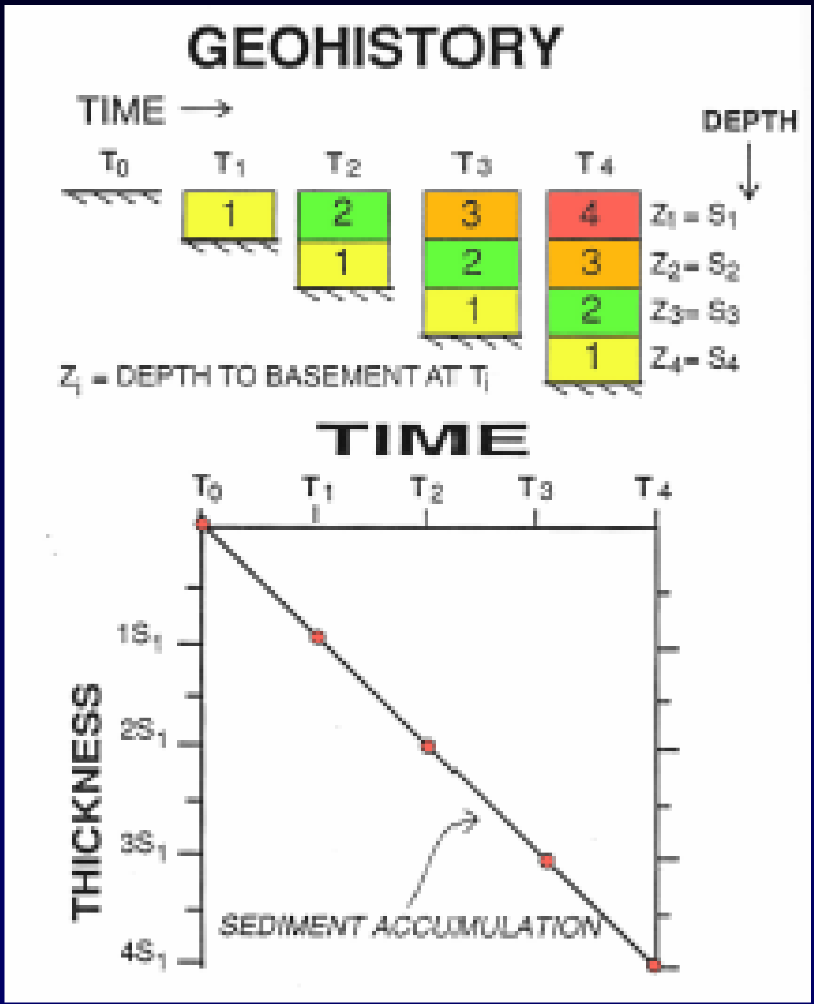
Simplified comparison

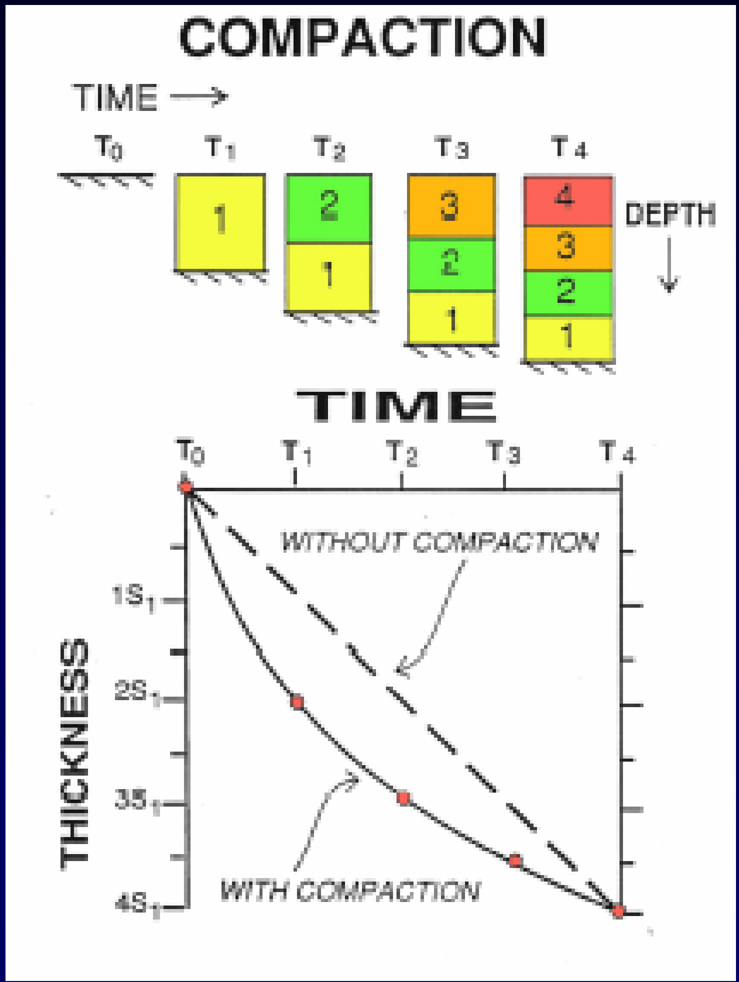
Stage	TTI	Ro	TAI
Onset oil generation	15	0.65	2.65
Peak oil generation	75	1.00	2.9
End oil generation	160	1.30	3.2
End wet gas generation	1500	2.2	3.75
End dry gas generation	65000	-	-

- Assumptions:
  - Both time and temperature are interchangeable variables in oil generation
    - Short time-high temp = long time-low temp
  - Dependence of maturity on time is linear: double the cooking time at constant temperature doubles the maturity

Lopatin TTI is a simple burial history model

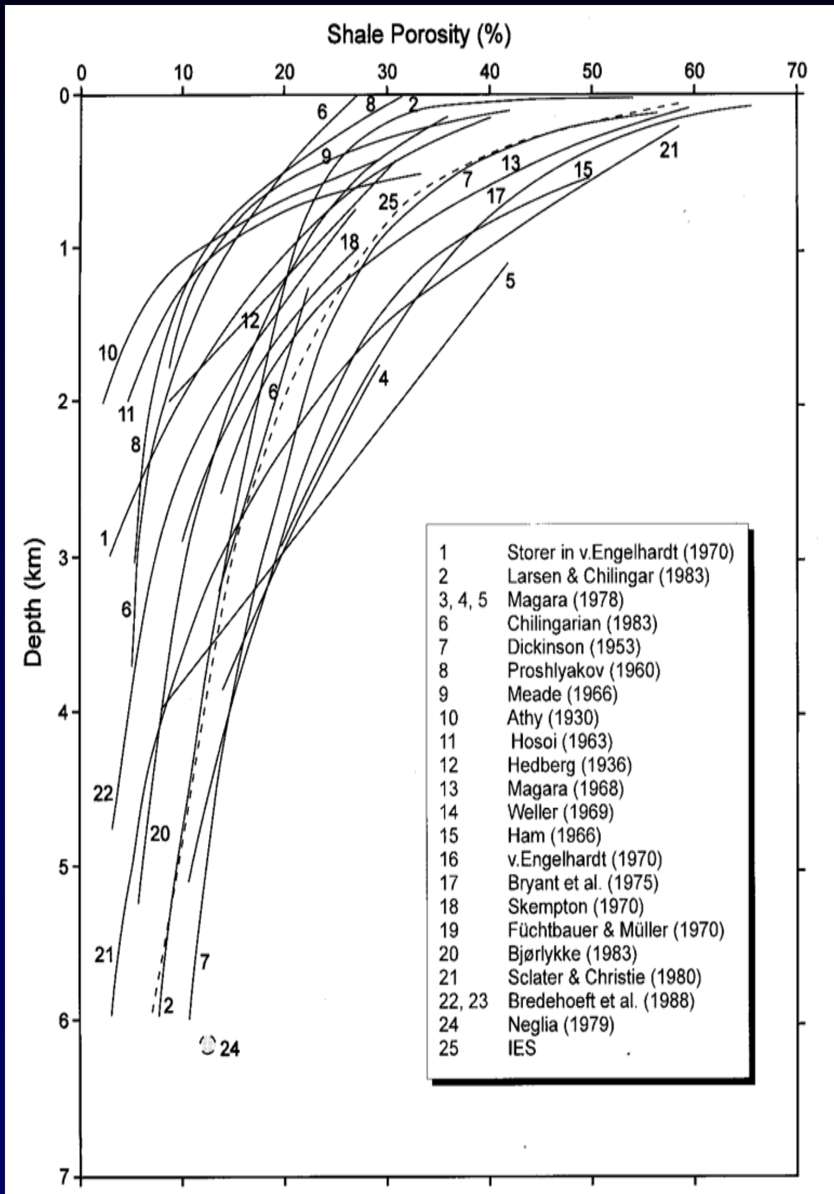
- ignores compaction effects





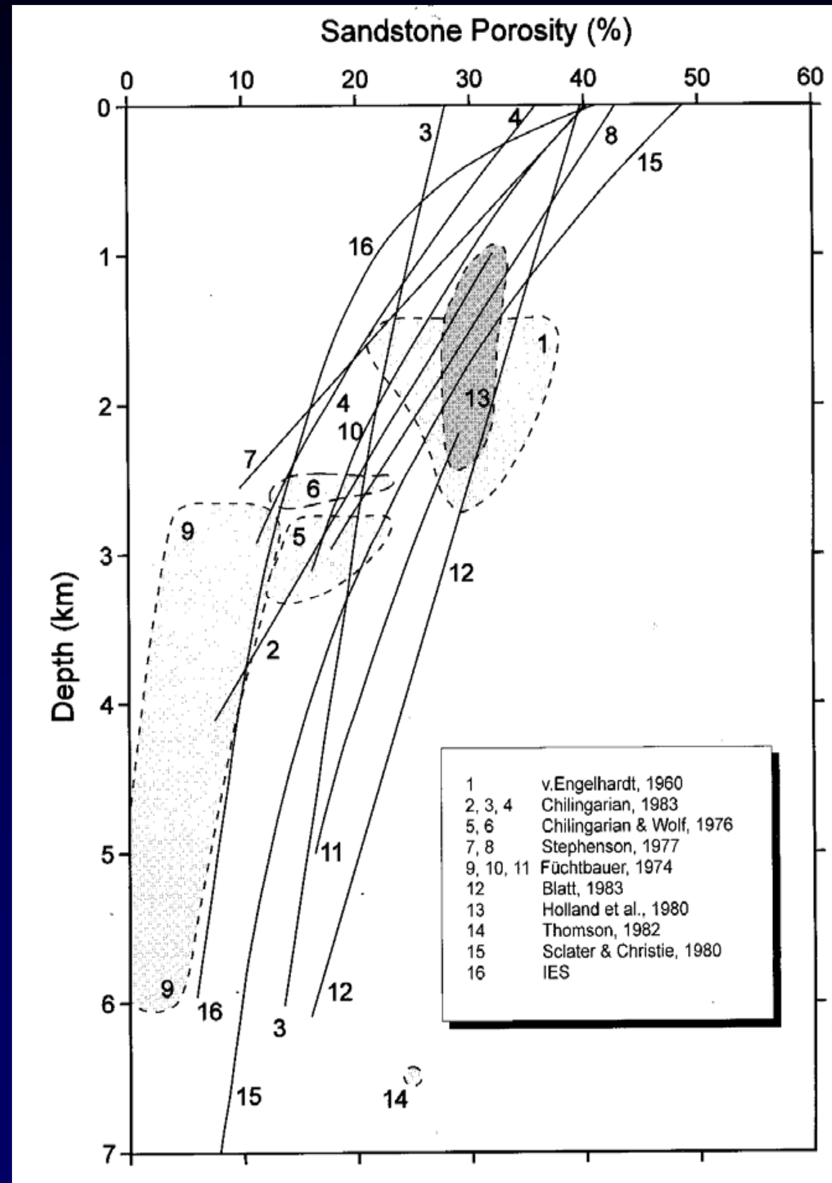
(Angevine, Heller & Paola, 1993)

Porosity Depth Curves: Shales



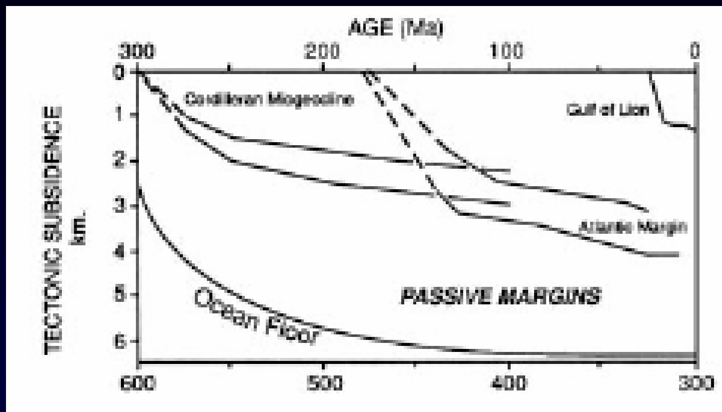
Source: Wygrala, 1989

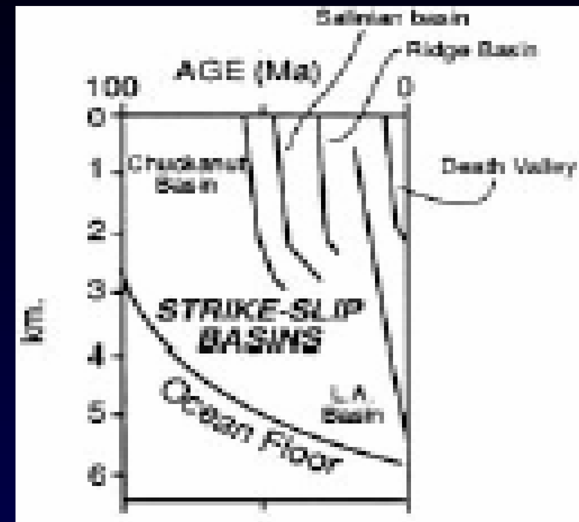
Porosity Depth Curves: Sandstones

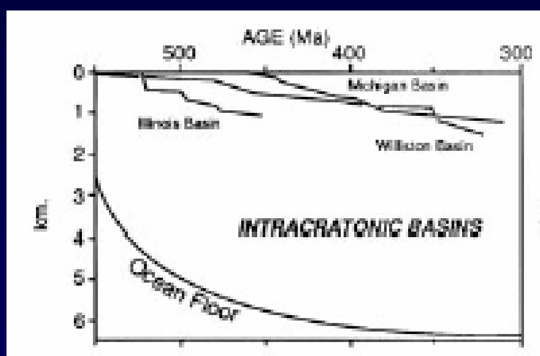


Source: Wygrala, 198

Tectonic Subsidence History

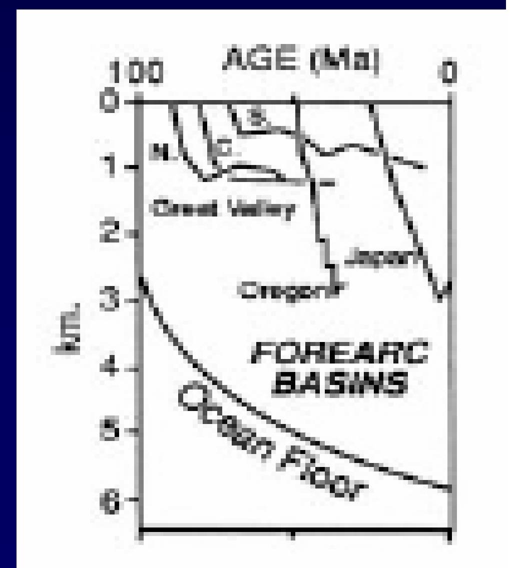


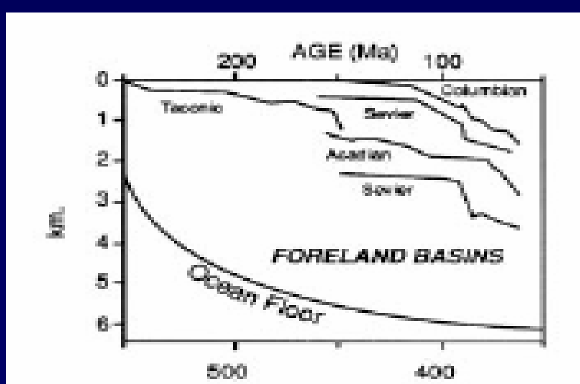




- useful in explaining the basin-forming mechanism

- obtained after removal of the subsidence due to sediment load & corrections for variation in water depth & eustatic sea-level changes.





source: Angevine, Heller & Paola, 1993

Organic-rich Source Rock → Thermally Matured Organic Matter → Oil

The temperature distribution in a basin is the result of HEAT TRANSFER

HEAT TRANSFER =

HEAT FLOW + HEAT SOURCE/SINK

Method of Heat Transfer

- **Conduction**
  - Heat transferred through a solid
  - Always important
- **Convection**
  - Heat transferred by fluids
  - Important if hydrothermalism
- **Radiation**
  - Generated by radioactive decay
  - Important in the crust

Estimating Radiogenic Heat Production from GR Logs

$$A = 0.0158 \cdot (API - 0.8)$$

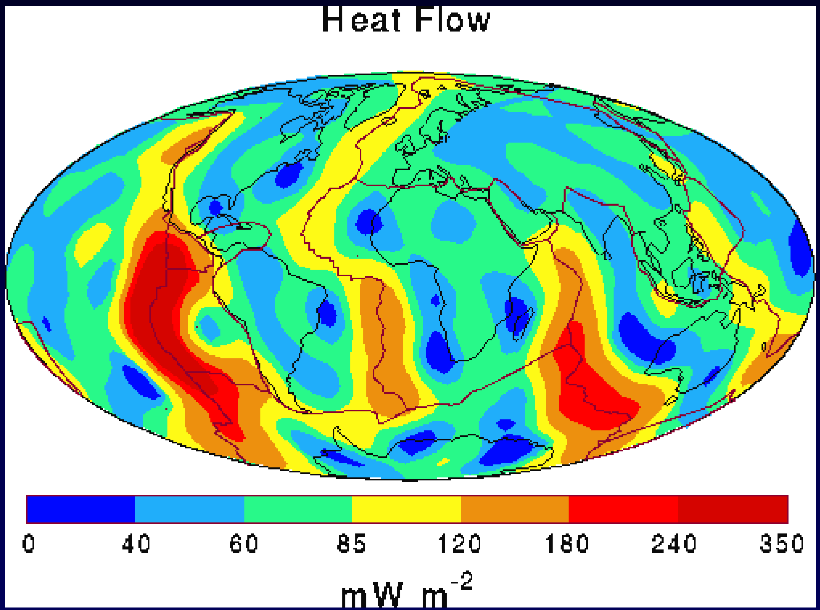
(Bücker & Rybach, 1996)

Heat Flow

- The heat flux measures how much energy is flowing through a given surface
- in sedimentary basins,
  - the standard unit is mW/m^2
  - HFU (heat flow unit) 1HFU=41.8 mW/m^2
- Orders of magnitude
  - 40 to 100 mW/m2 on continental crusts
  - 50 to 300 mW/m2 on oceanic crusts

Contributors to Surface Heat Flow

- Sediments
  - Gamma ray API
- Crust
  - strong variations with crust nature/age
  - usually described as decreasing exponentially with depth :
    A = Ao exp (-z/zc)
- Lithospheric Mantle
  - varies with age and composition of the lithosphere
  - depth of the lithosphere/astenosphere boundary
- Asthenospheric (limit 1300°C)
  - convective mantle
  - radiogenic source



Temperature Data

• Borehole temperatures (BHT) need to be corrected from the cooling of the mud circulation, using Horner Plot corrections or statistical methods.

• Production tests which are more reliable but rare in exploratory wells (DST, RFT).

Visuals of coals as a function of thermal evolution

Peat

Dull Lignite
Brown coal

Bright Lignite
Brown coal

Bituminous coal

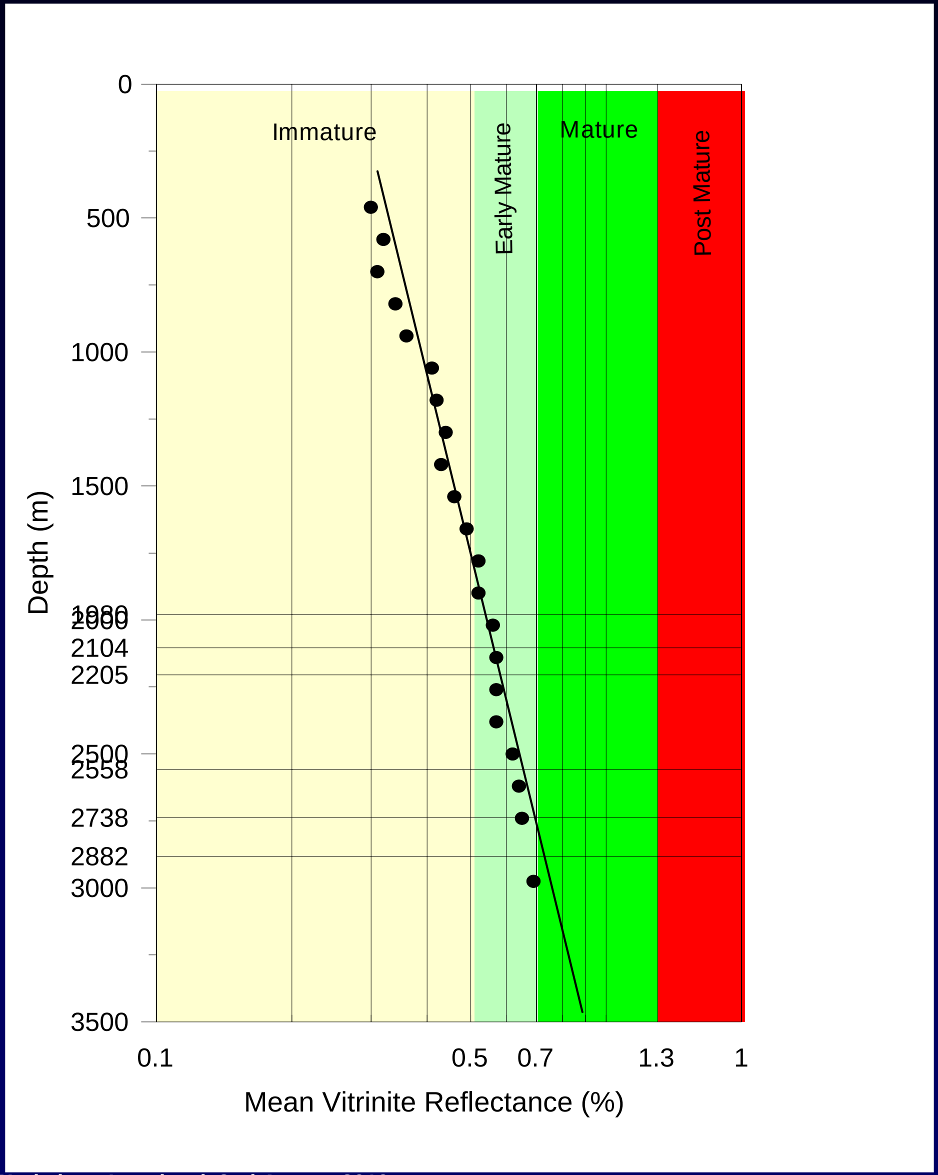
Anthracite

Maturity Determination of Source Rock

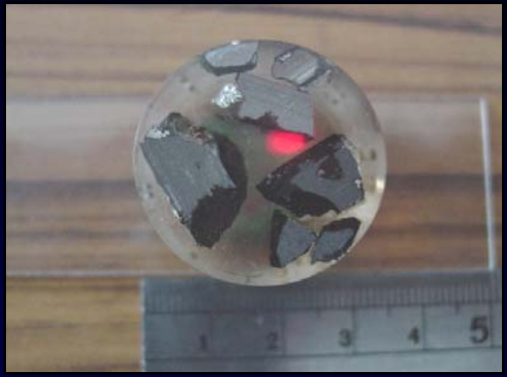
- **Vitrinite Reflectance – most commonly used**
- **Spore Colouration Index (SCI)**
- **Biomarker maturity ratios**

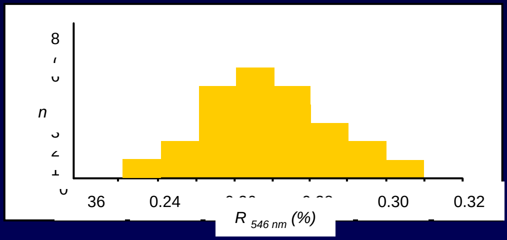
Vitrinite Reflectance

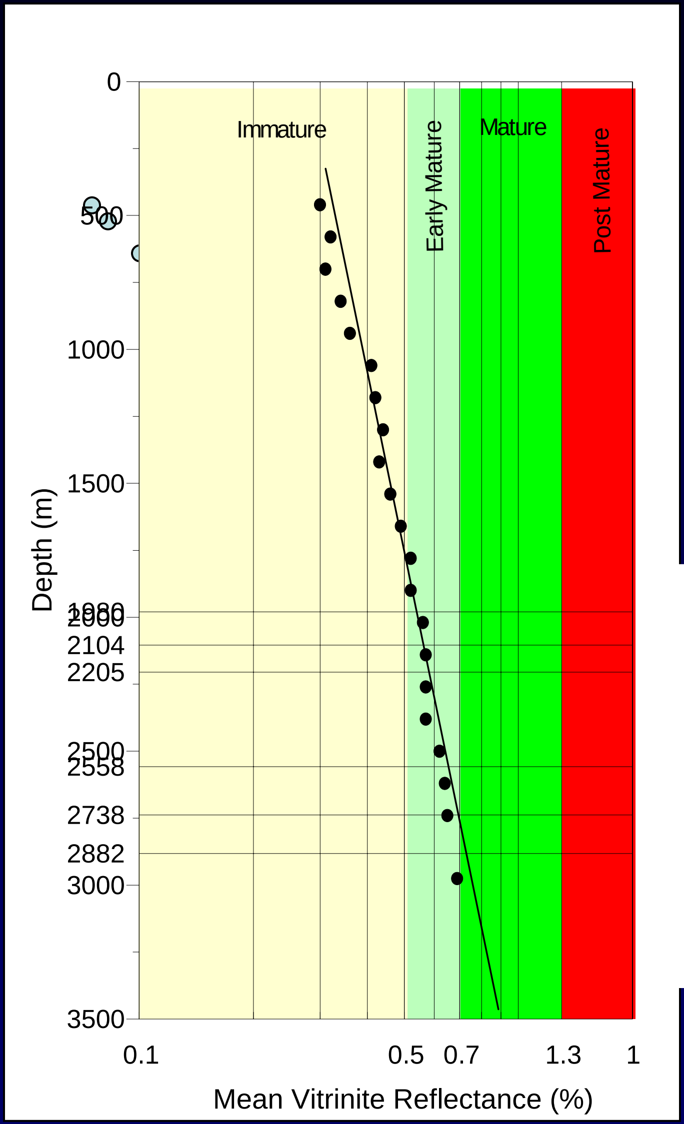
< 0.5 : **Immature**
0.5 – 0.7 : **Early mature**
0.7 – 1.3 : **Mature**
1.3 – 2.0 : **Post-mature**



Process Flow: Maturity Modelling
Calibrate with actual measured data







Advantages & disadvantages of VR

Advantages :

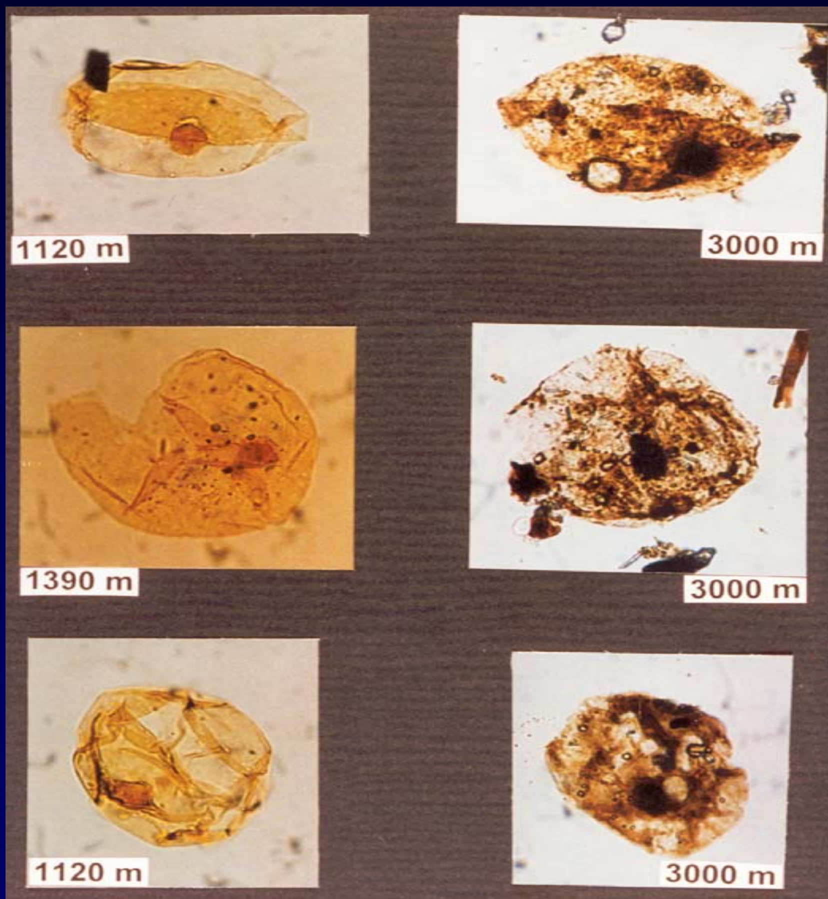
- extensively used in basin model
- wide range of maturity ranges
- technique simple, cheap and quick
- vitrinite is common in post-silurian basins

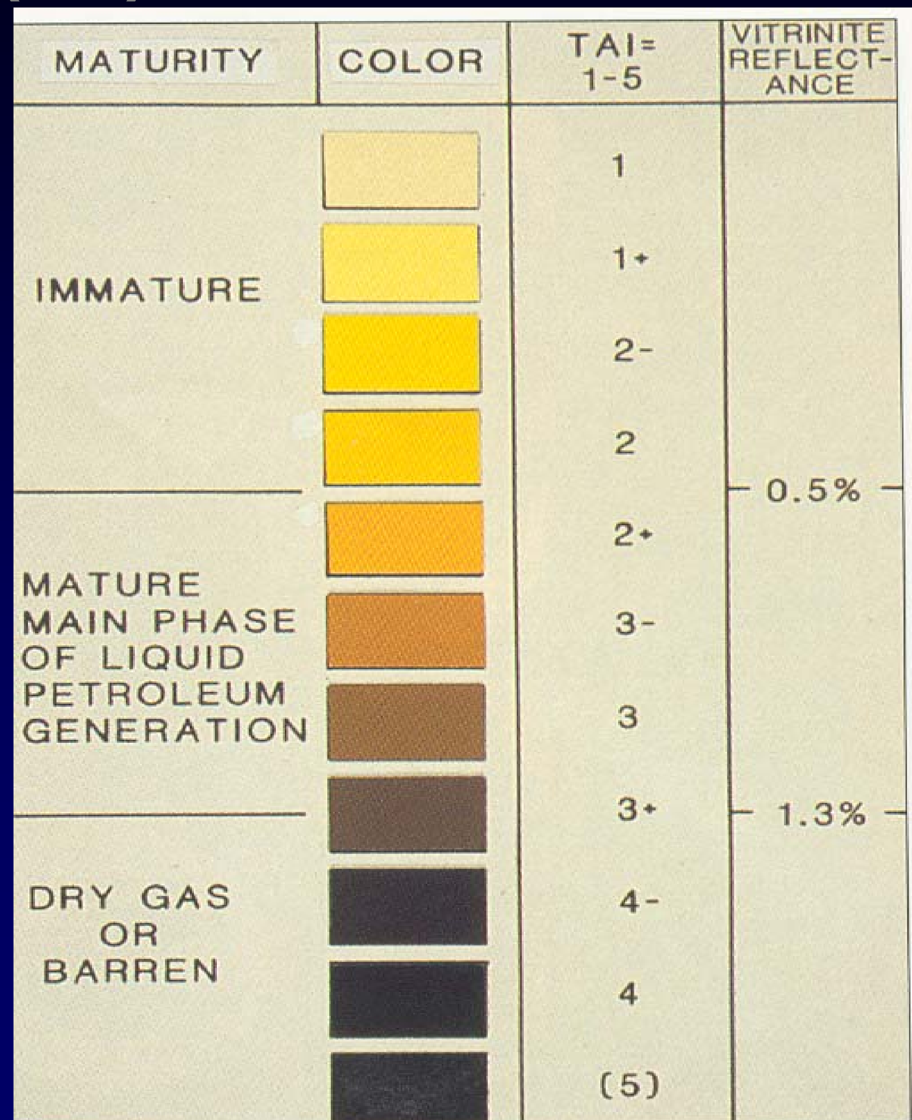
Disadvantages :

- analysis subject to human error
- identification of 'true' vitrinite from cavings, recycled, oxydized, mud additives.
- subjects to polishing quality
- perhydrous vitrinites
- absent in pre-Silurian

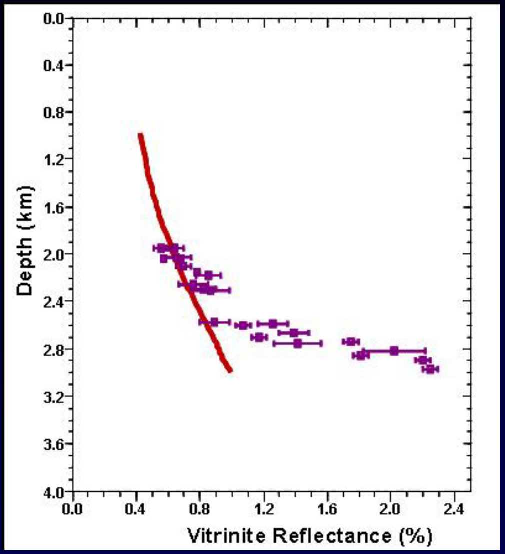
Maturity Determination of Source Rock

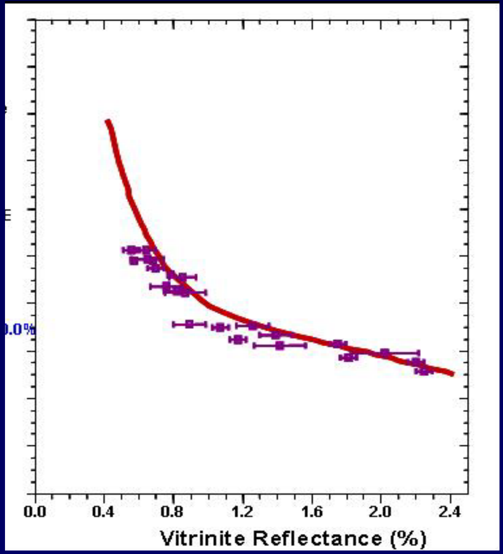
Spore Colouration Index (SCI)



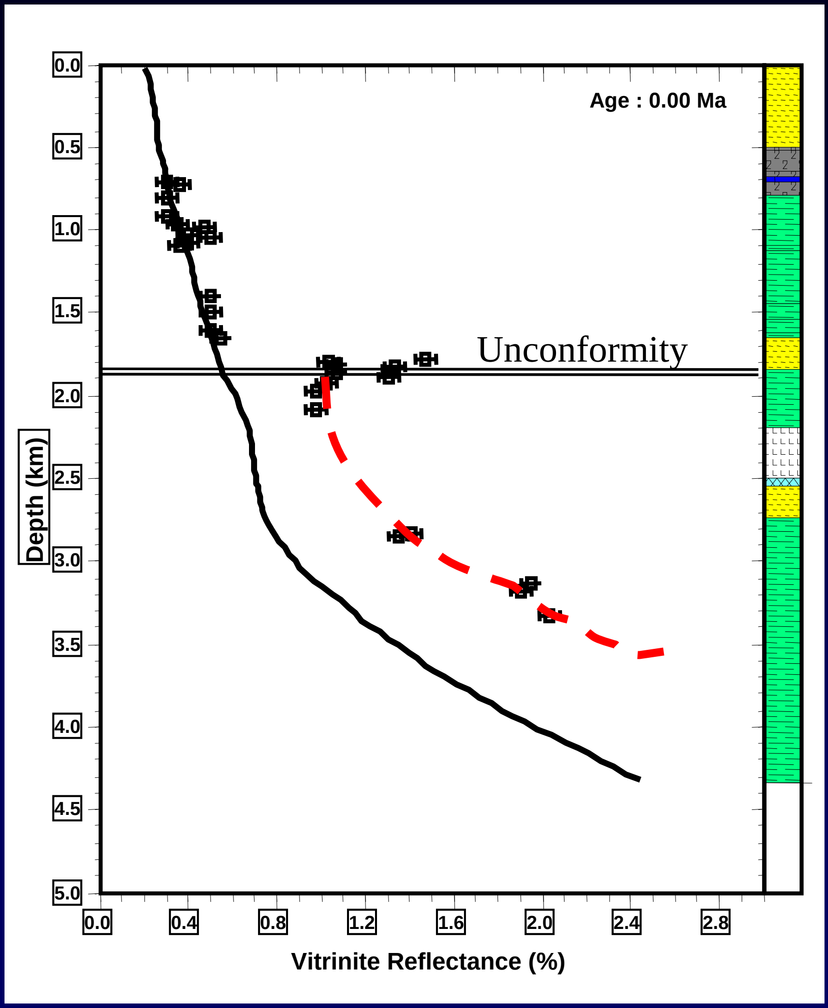


Paleo heat flow from maturity calibration



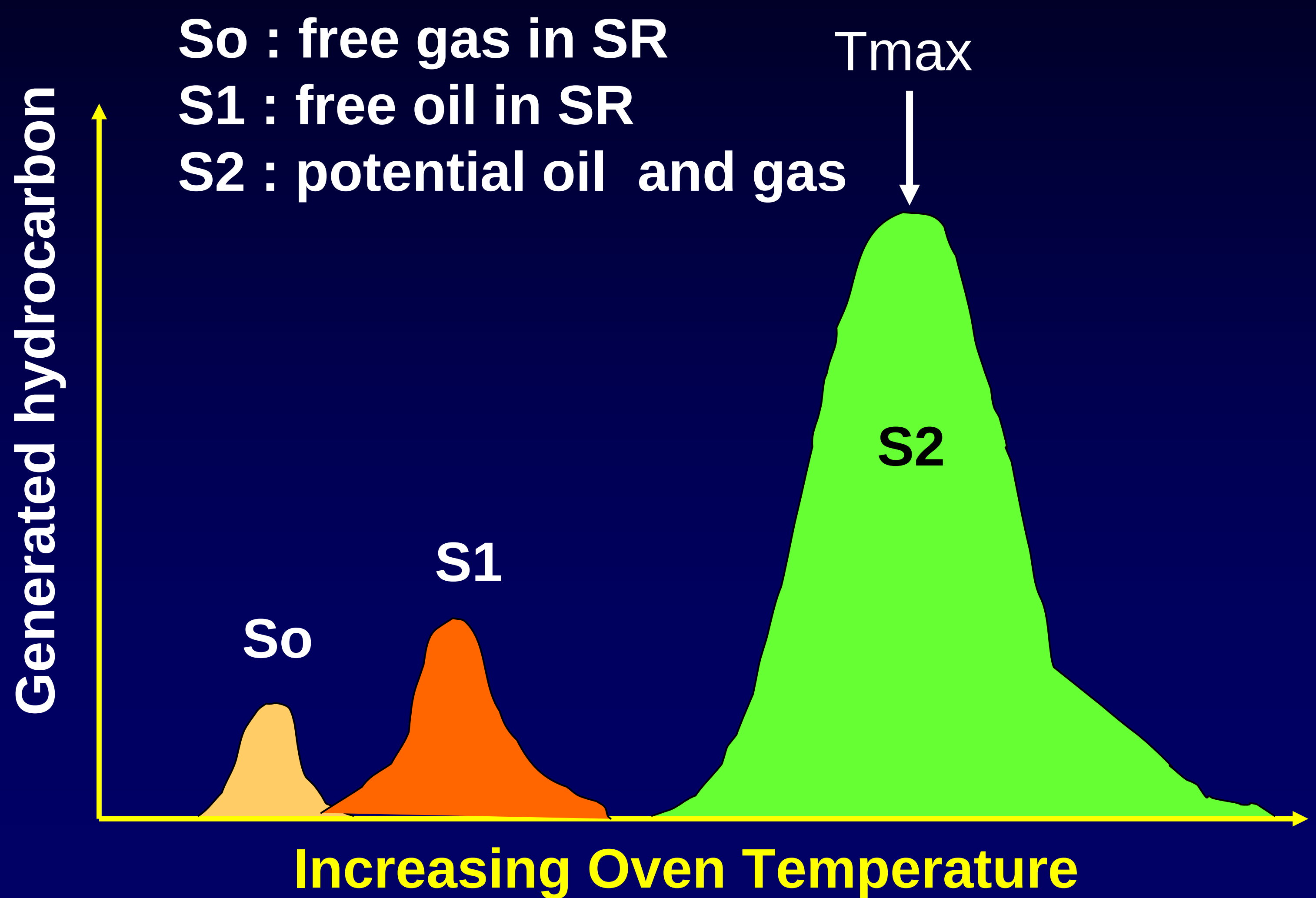


warmer thermal regime in the past

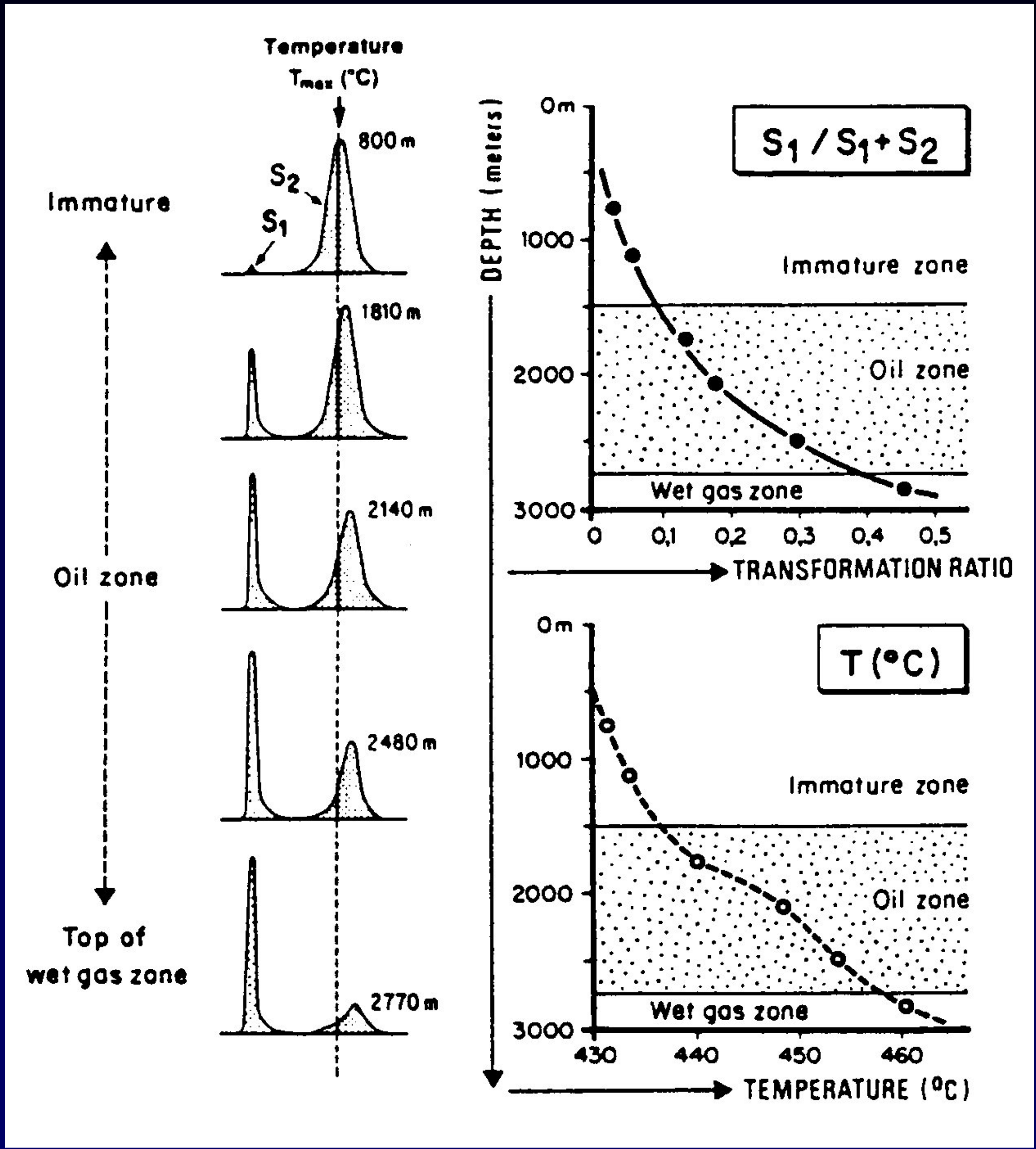


effect of erosion on vitrinite profile

Source Rock Characterization
Rock-Eval Parameters



Changes in TR and Tmax



Espitalie et al., 1977

Darcy’s law

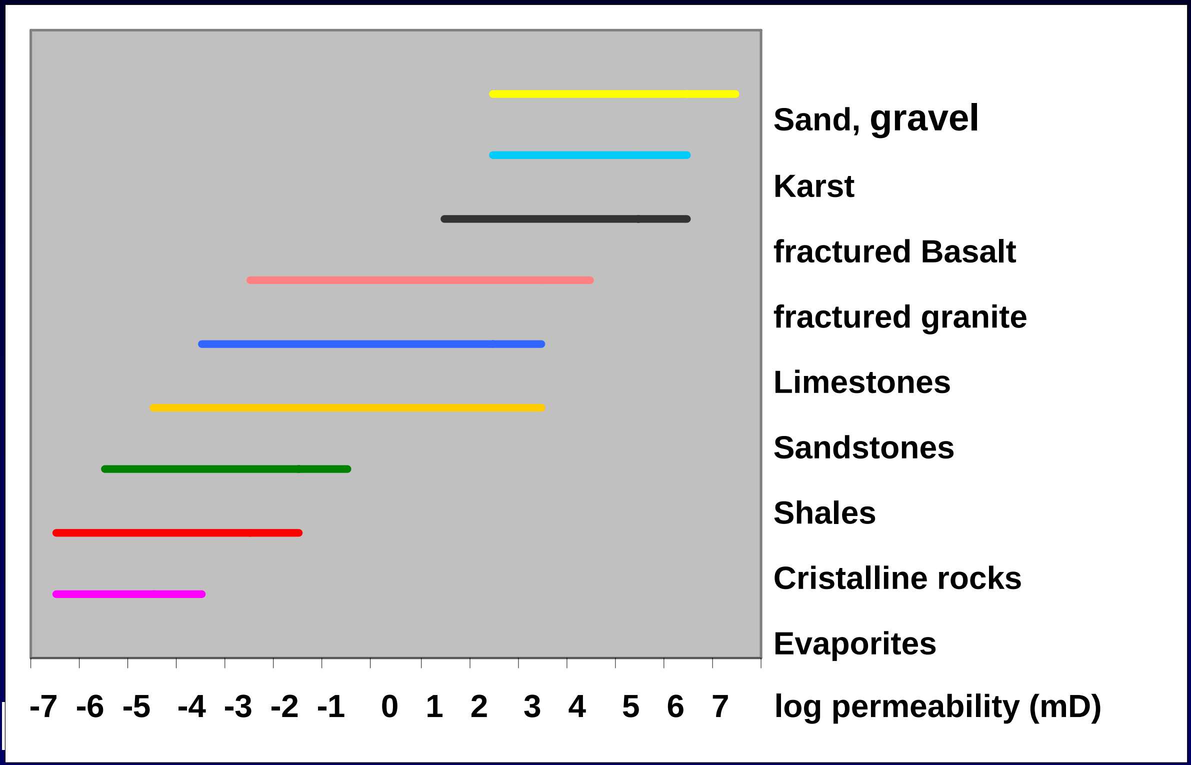
$$Q = KA\frac{Z_2 - Z_1}{L}$$

- **fluid volume flux is proportional to cross sectional area, height difference and permeability of porous medium**

- **if permeability is low, the flow is slow**

Permeability of rocks

Permeability varies over many orders of magnitude



Unit of permeability: 1 mD (milliDarcy) = 10^{-15} m^2

Kozeny - Carman formula

if $\phi > 0.1$

$$K = \frac{0.2\phi^3}{S_0^{\ 2}(1-\phi)^2}$$

if $\phi \leq 0.1$

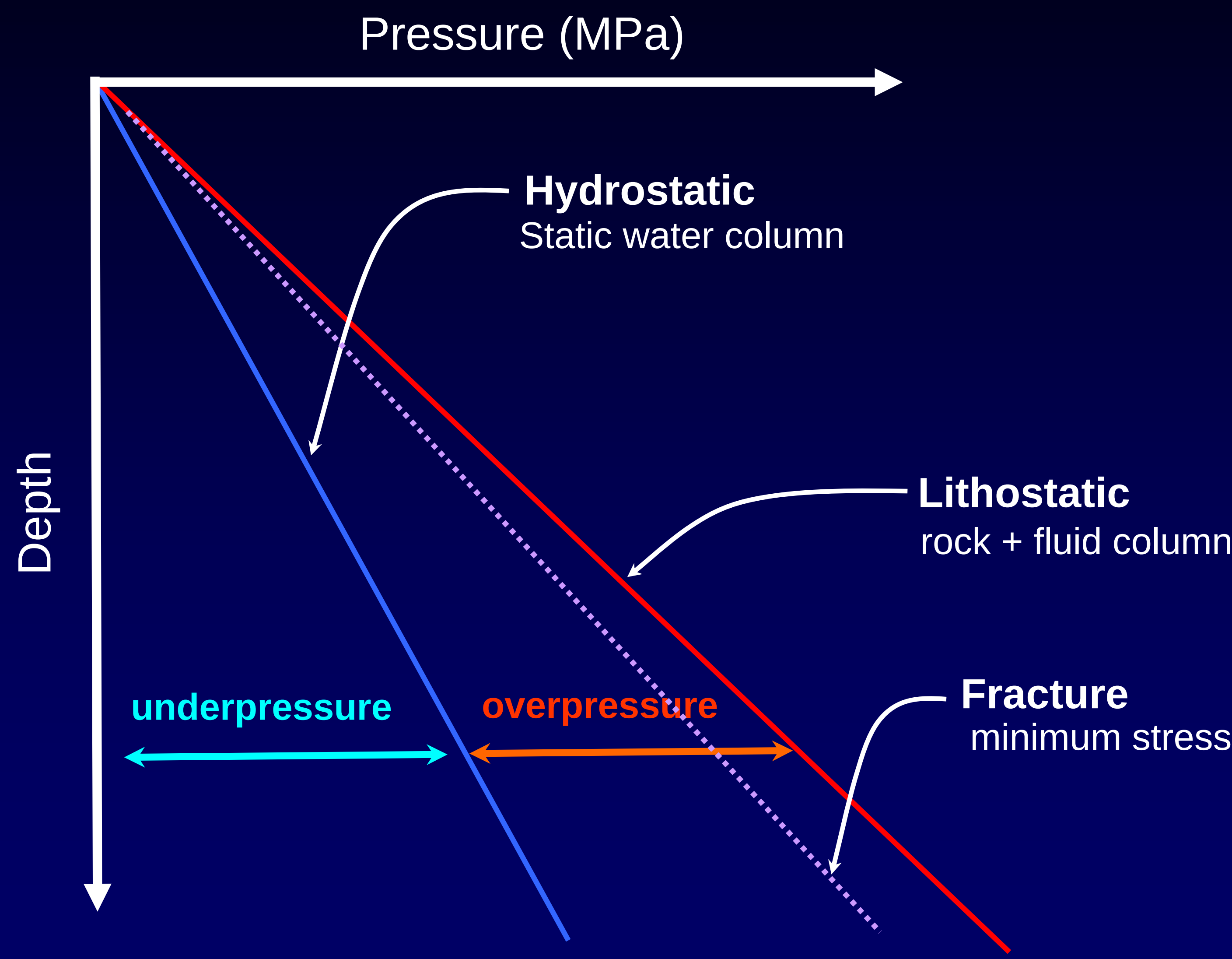
$$K = \frac{20\phi^5}{S_0^{\ 2}(1-\phi)^2}$$

K : **intrinsic permeability (m^2)**

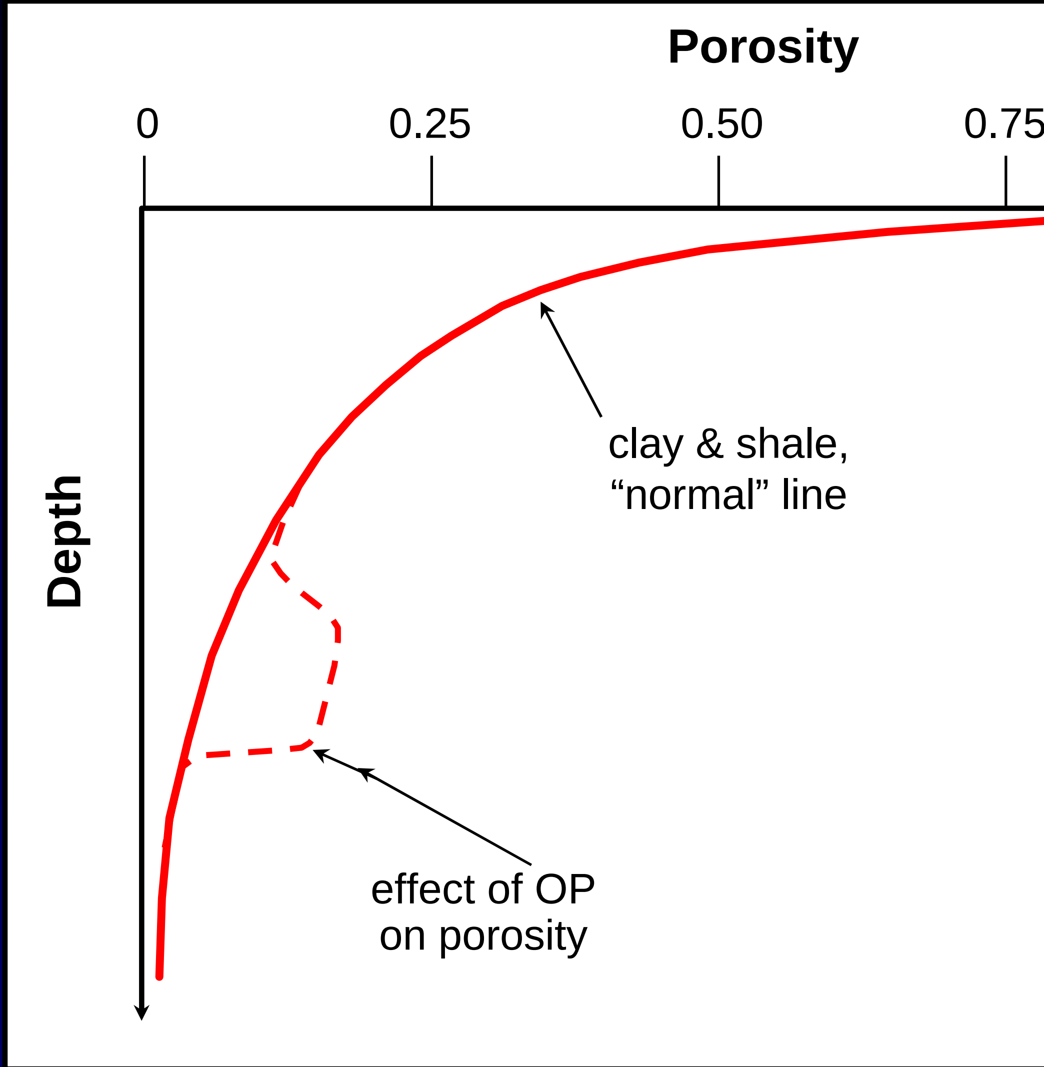
S_0 : **specific surface area (m^2/m^3)**

ϕ : **porosity**

Pressure Depth Profile



Porosity vs Depth: Undercompaction



Anomalously high ϕ, low v_P, v_S, and other properties may indicate OP

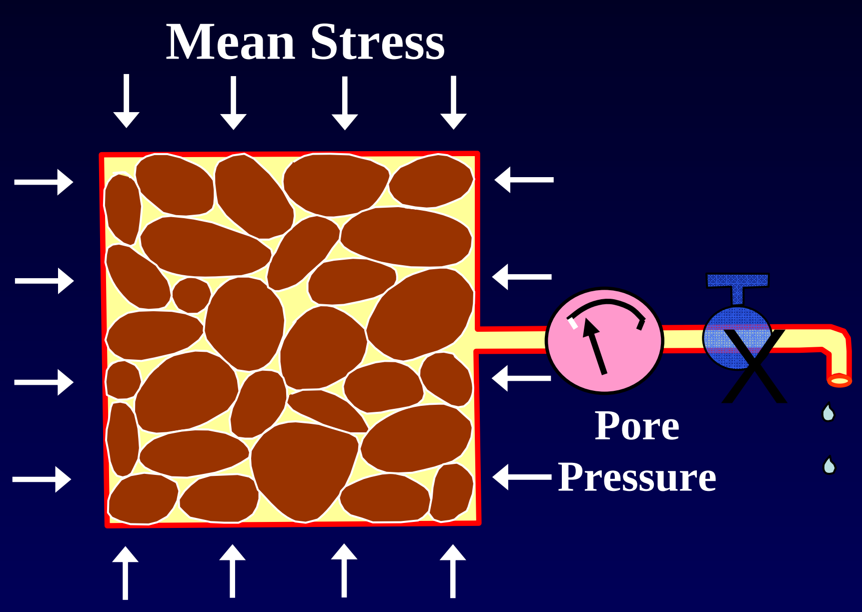
Overpressuring Mechanisms:

- **Loading Stress** :

- **Volume change/Unloading** :

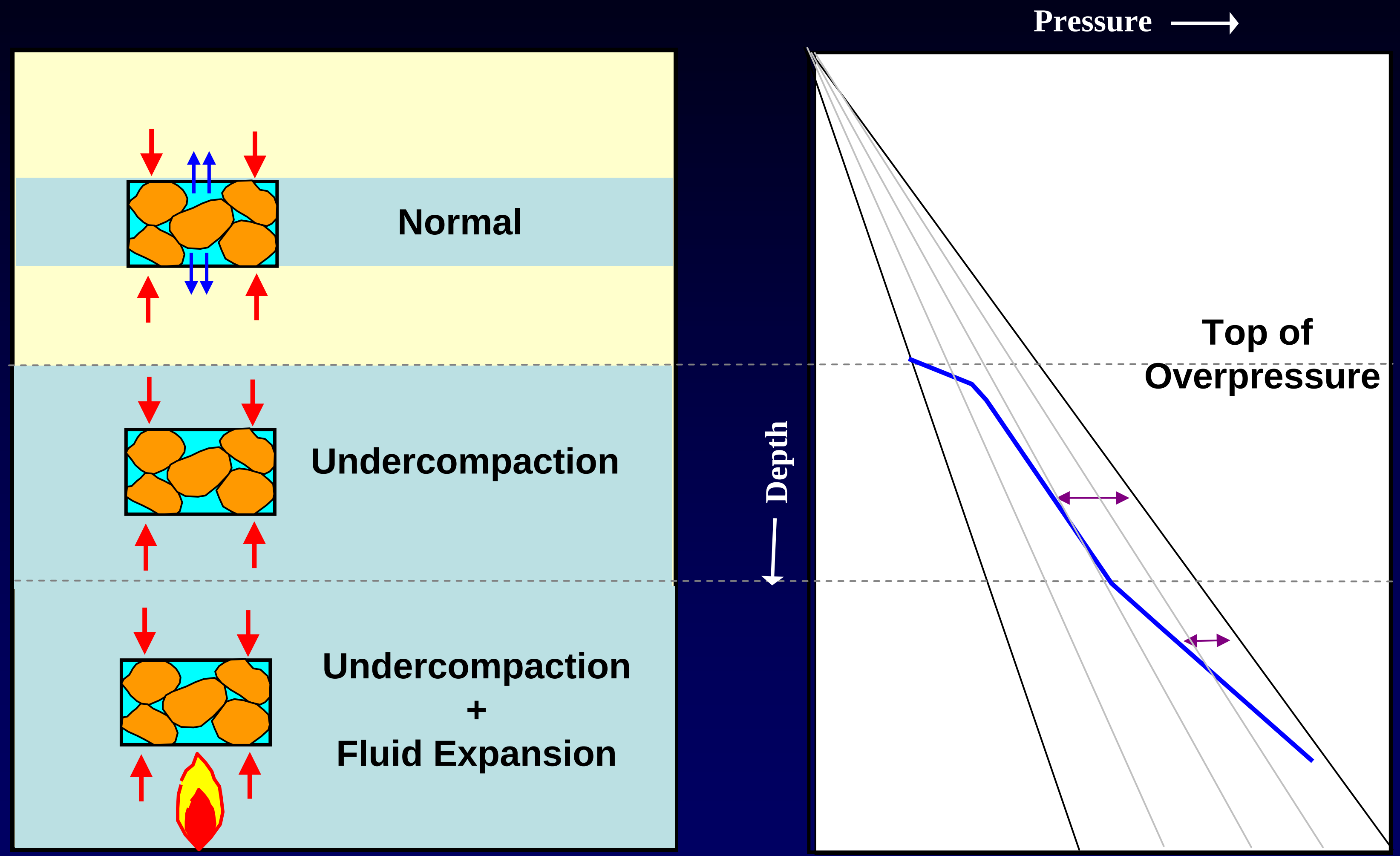
- **Fluid Movement & Others** :

Disequilibrium Compaction



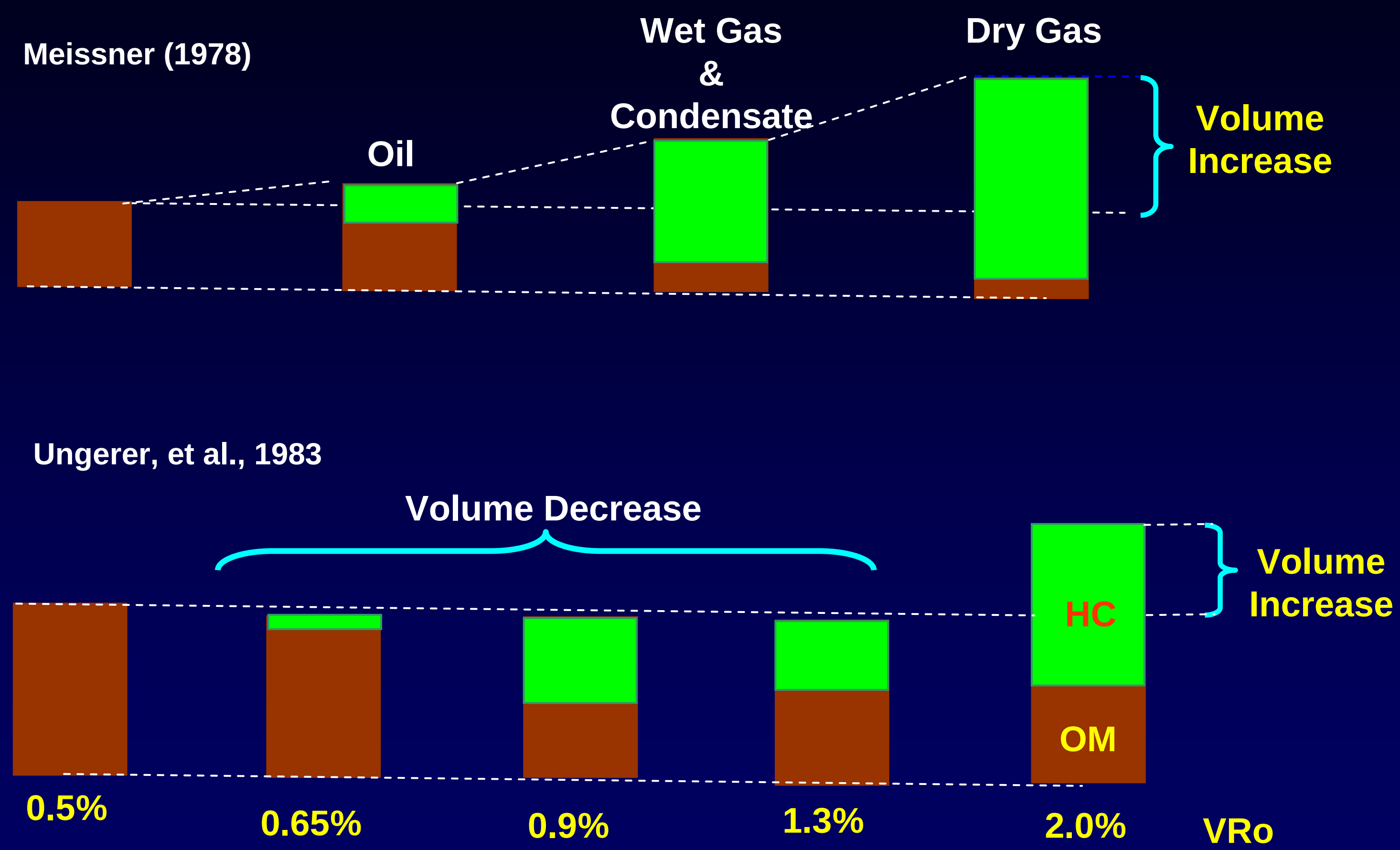
- Ineffective dewatering of pore fluids
- Low permeability & high sedimentation rates

Volume Expansion



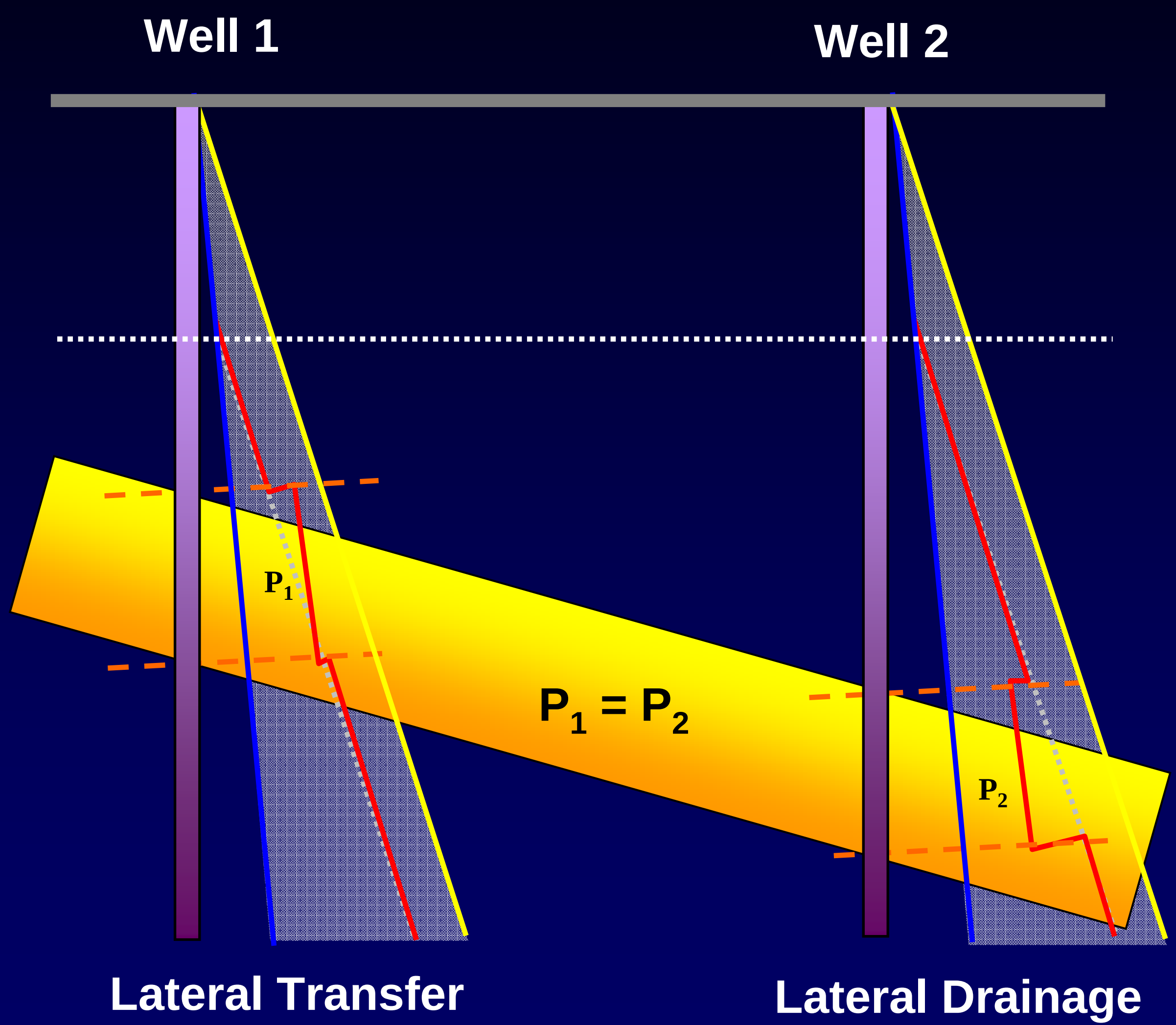
(Bowers, 2001)

Hydrocarbon Generation



Swarbrick, et al. (1998)

Lateral Transfer & Lateral Drainage



Pre-drill pore pressure prediction Methods

- Log Analysis of Offset Wells
- Seismic Velocity
- Basin Modelling

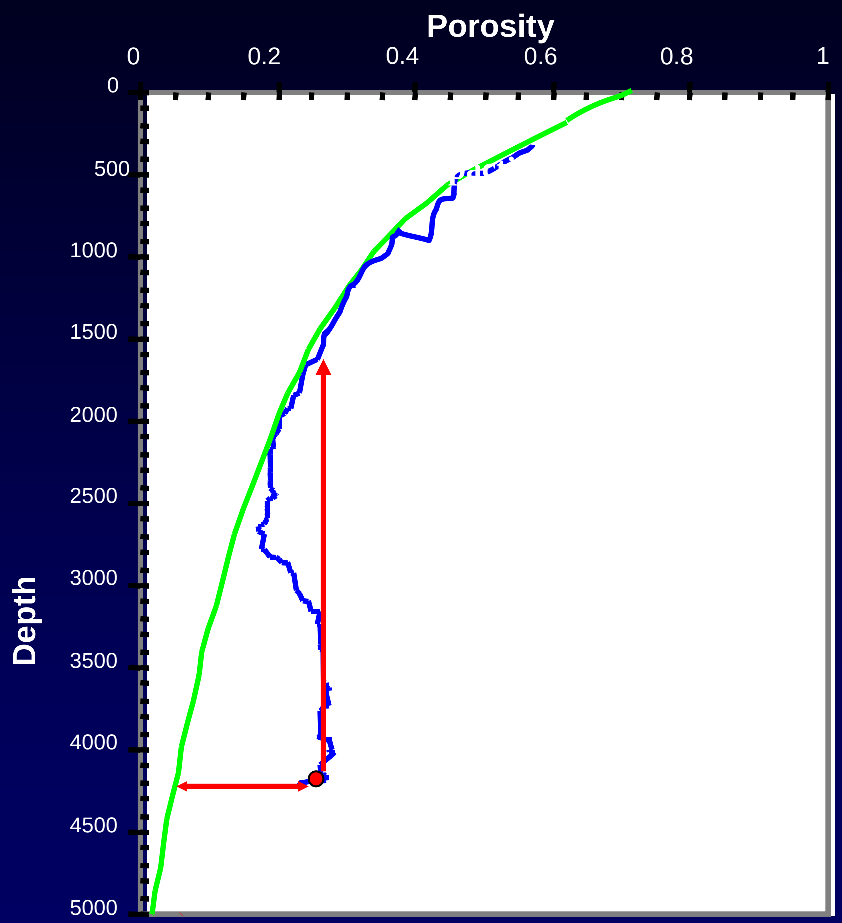
Pore Pressure Prediction Methods

Graphs

Ratio
- Hottman & Johnson (1965)
- Eaton (1972)

Equivalent Depth
- Forster & Whelan (1966)
- Magara (1968)
- Dobrynin & Serebryakov (1978)
- Hart et al (1995)
- Harrold et al (1999)
- Bowers (2001)

Constitutive Equation
- Dutta (1988)
- Dobrynin & Serebryakov (1989)



Terzhagi (1923) defined effective stress (σ) as the difference between normal stress (S) and pore pressure (Pf).

$$\sigma = S - P_f$$

PRINCIPLES OF EDM & EATON:

- **Disequilibrium compaction only**:
  - Mechanical compaction
  - Empirical or soil mechanics
- **Porosity-based methods** :
  - Porosity relationships
  - Normal compaction curves
  - Lithologic controls

CAUSAL MECHANISMS :

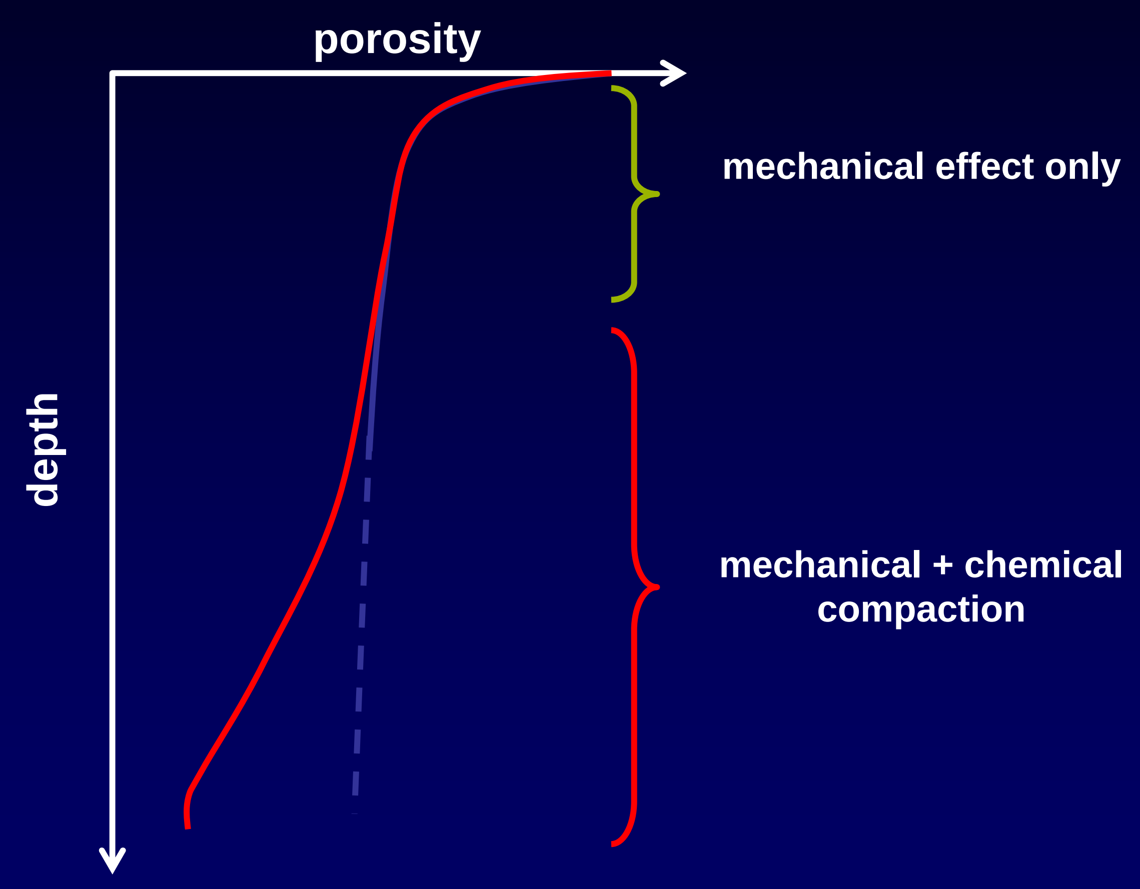
- Disequilibrium Compaction
- Hydrocarbon Generation & Cracking
- Aquathermal Pressuring
- Clay Dewatering
- Clay Diagenesis
- Lateral Transfer

PRESSURE PREDICTION METHODS :

- Equivalent Depth
- Empirical Ratio (e.g Eaton)

Need to understand the origins !

Chemical compaction



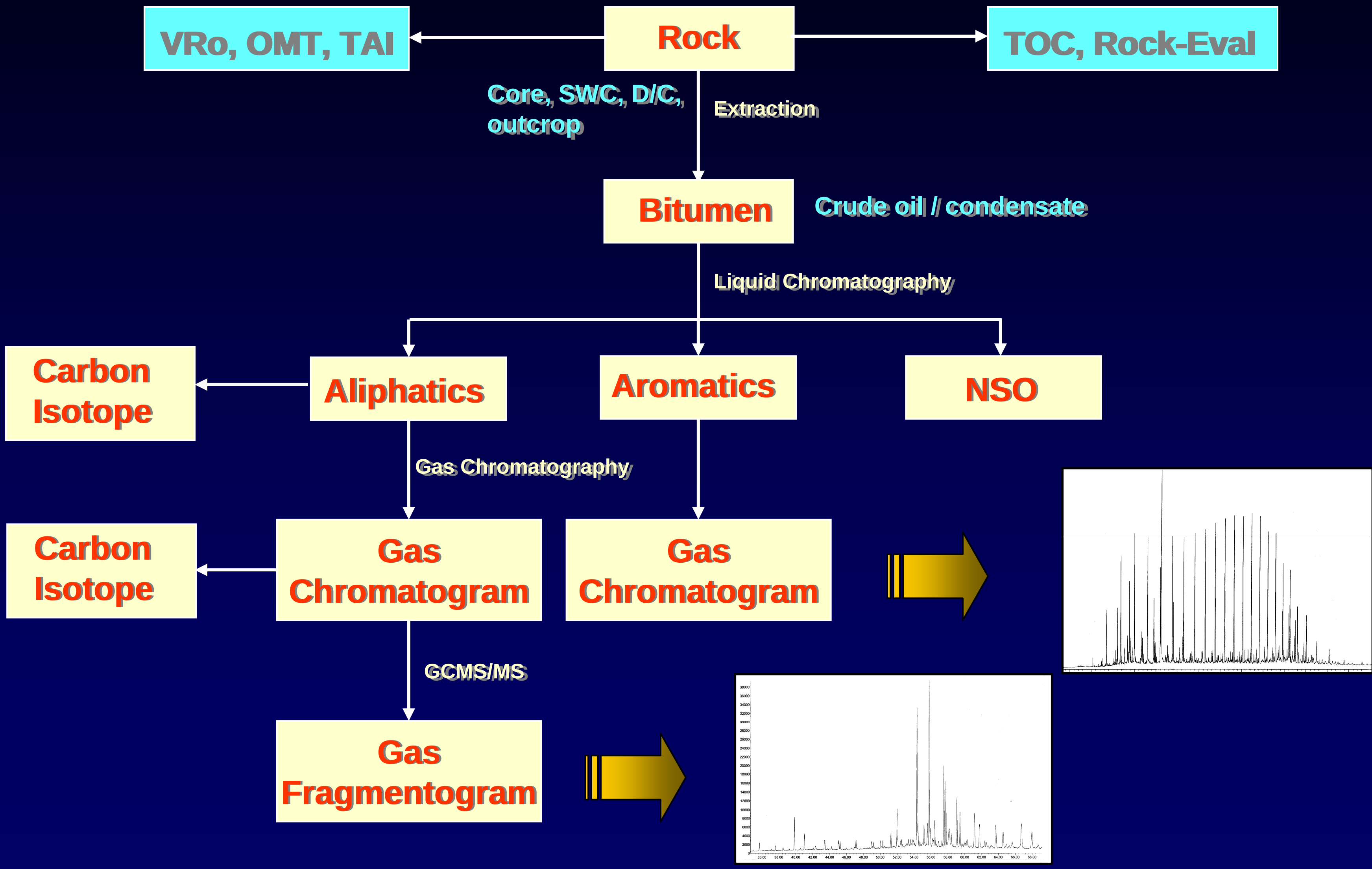
Source Rock

Rock containing suitable amount and type of organic matter and capable of generating hydrocarbons given the right maturity (temperature & pressure conditions).

- Quantity: does the rock contain sufficient quantity of organic matter to generate hydrocarbons?
- Quality of the organic matter : is the organic matter capable of generating oil or gas or both?
- Maturity of the organic matter : has the organic matter been heated sufficiently to generate petroleum?

Analytical Chart

PETRONAS RESEARCH



Petroleum Migration Processes

- Petroleum Expulsion
- Secondary Migration
- Tertiary Migration

Forces Controlling Migration Efficiency

- Buoyancy
- Capillary
- Pressure Gradient
- Others

Numerical Simulation

- Traditional Darcy Flow
- Invasion Percolation
- Ray-Tracing

Petroleum Migration

- **Primary Migration**

  Expulsion of petroleum out of the source rock into the carrier rock.

- **Secondary Migration**

  Along the carrier rock to the trap, including re-migration. Interplays between buoyancy, hydrodynamic and capillary pressure.

- **Tertiary Migration**

  Leakage out of the trap.

Migration mechanisms:

Mechanisms for primary migration:

(1) hc in water solution,

(2) micellar solution,

(3) emulsion,

(4) molecular diffusion, molecular film or

(5) as separate phase (oil, gas, oil dissolved in gas or gas dissolved in oil) moving along the kerogen network or through pore system.

Less likely HC expulsion in aqueous solution because of the amount of soluble HC fractions does not match with the expected found in the typical crude oils.

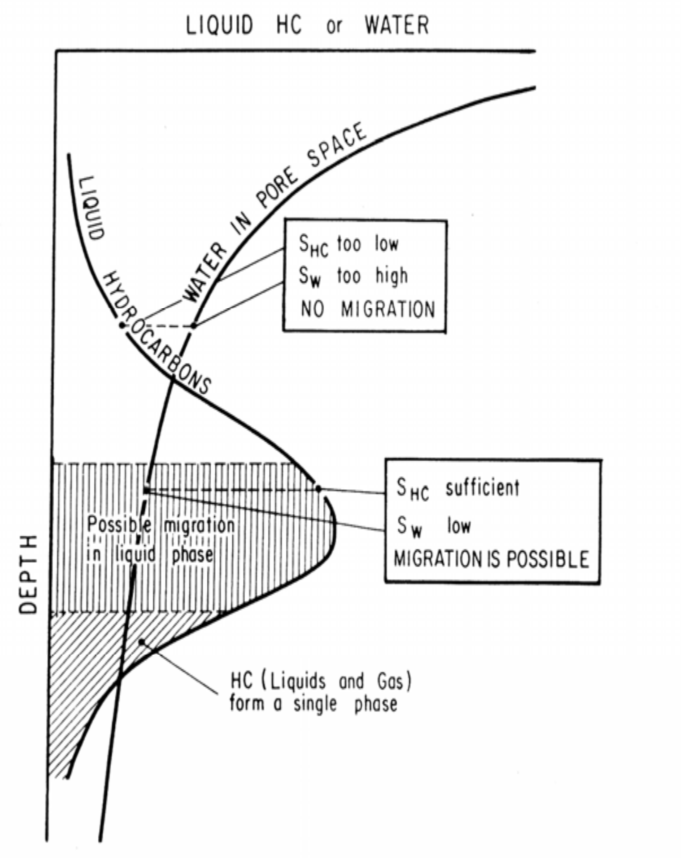


FIGURE 1 Compared quantities of water and liquid hydrocarbons in source rocks, as a function of depth/time

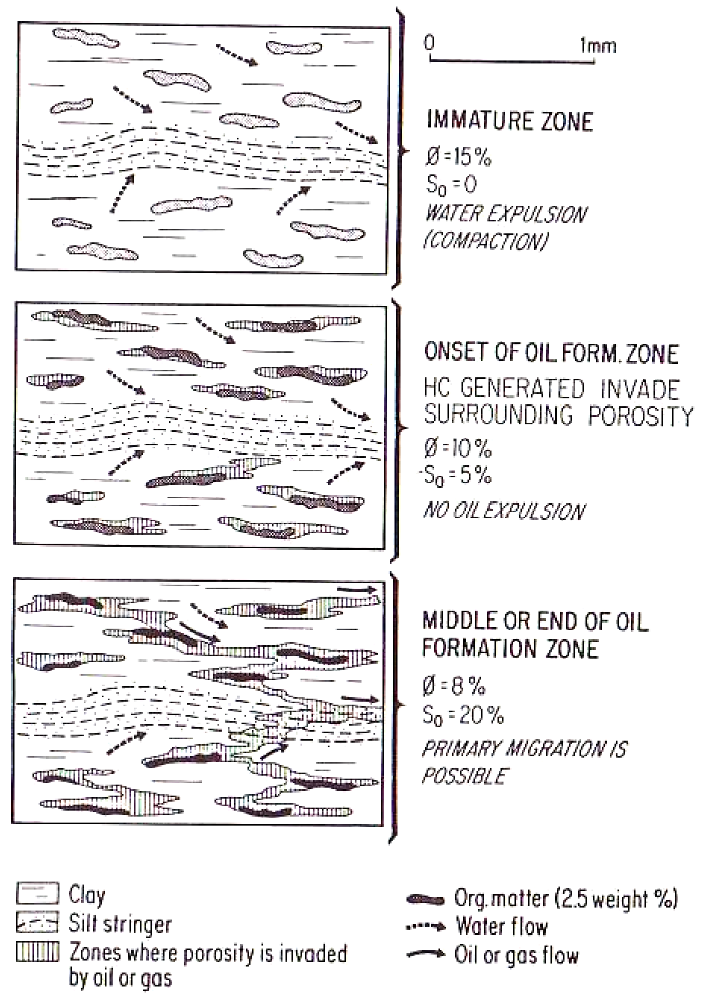
Primary Migration

• Modeled using pressure-driven two-phase fluid-flow in compacting porous medium or using minimum oil saturation as a necessary condition to the formation of an oil-wet network in a source rock before expulsion

• Therefore treated empirically, calibrated from geochemical data

•Through diffusion when a continous organic netwrok is present (Stainforth & Reinders, 1990)

Formation and expulsion of oil in a source rock. Sketch by P. Ungerer (unpublished).



Primary Migration

- Rapid expulsion before oil cracking favors oil accumulation

- Late expulsion allows for oil cracking inside the source rock, leading to gas accumulation

- The physics of expulsion is not well known to give predictive values of saturation threshold or the relative permeabilities

- Modelled: (1) saturation threshold, or (2) pressure-driven fluid-flow

- Use the amount of free hydrocarbons in mature source rocks (Rock-Eval S1) to calibrate expulsion

Secondary Migration

Must reach minimum saturation before oil can flow.

Seek tortuous path of least resistance

Saturation resulted volumetric loss associated with migration

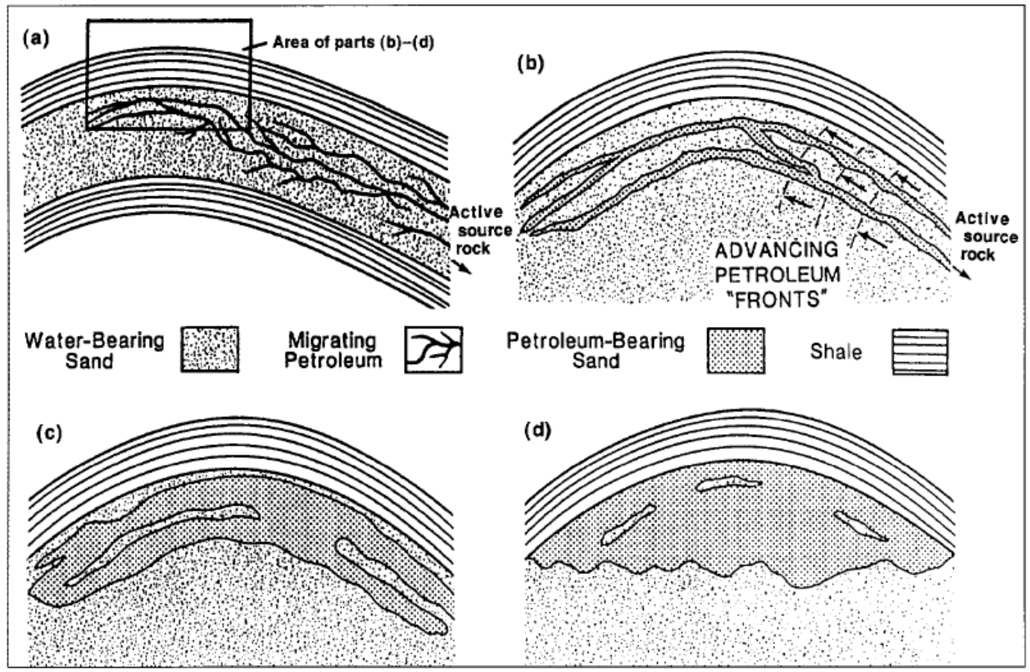
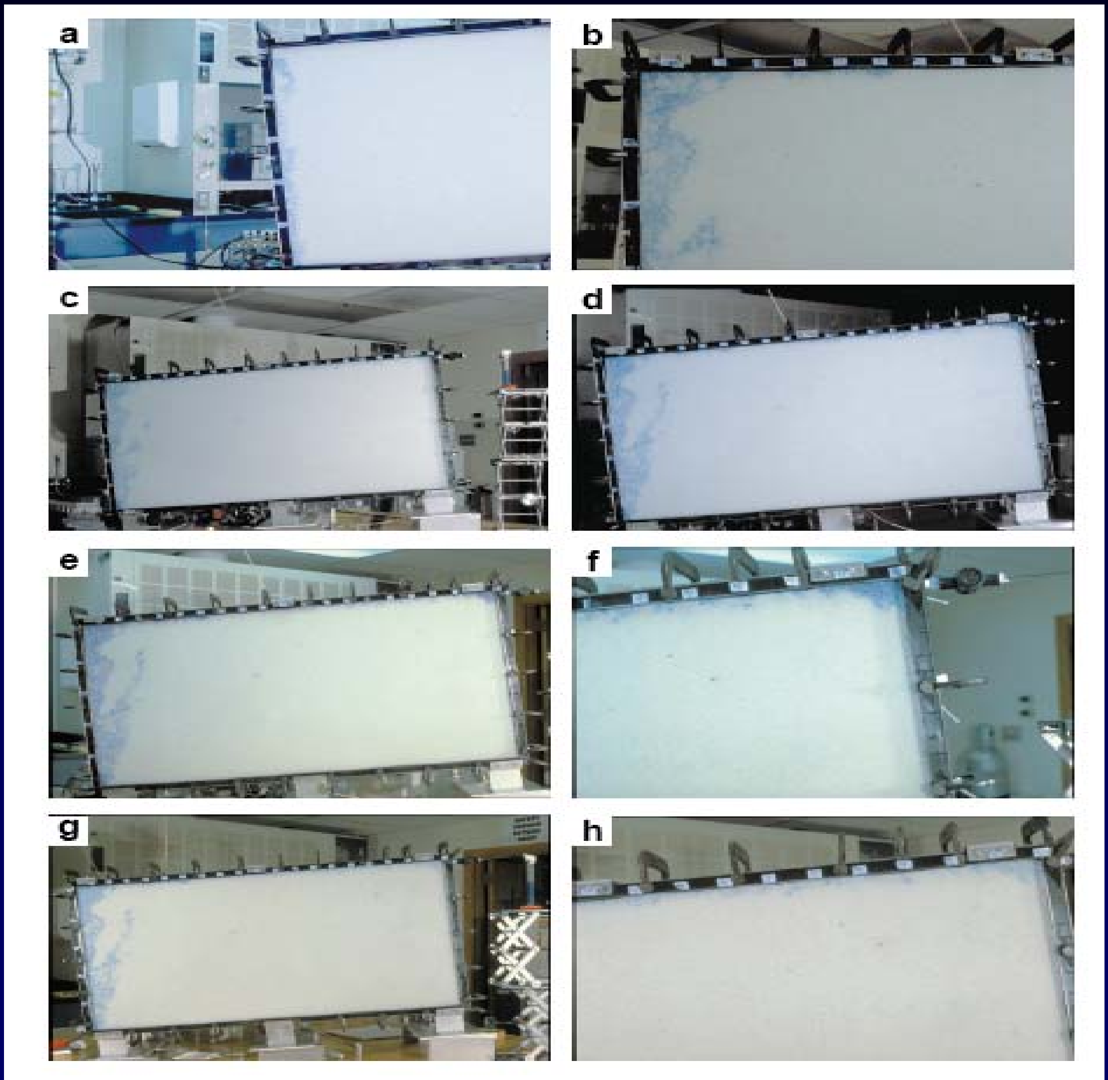


Figure 12.3. Reservoir filling. (a) Petroleum migrating into a trap from a pod of active source rock to the right of the diagram. (b) During the initial filling process, the coarsest beds are filled first with petroleum. Widespread mixing is impossible due to poor reservoir-wide connectivity. (c) and (d) The increasing column height causes other (but not all) parts of the reservoir rock to become saturated with petroleum.

Laboratory experiment of petroleum migration (Thomas and Clouse, 1995)



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Buoyancy

Pressure difference between a point in the petroleum column and the surrounding pore water.

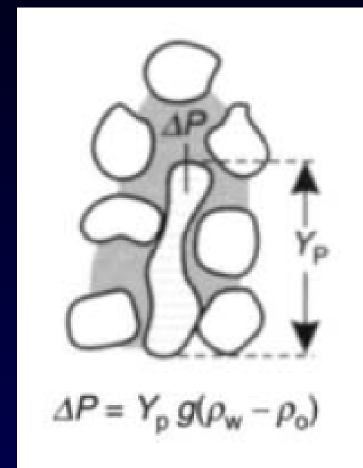
$$\text{buoyancy force } \Delta P = Y_p g(\rho_w - \rho_p)$$

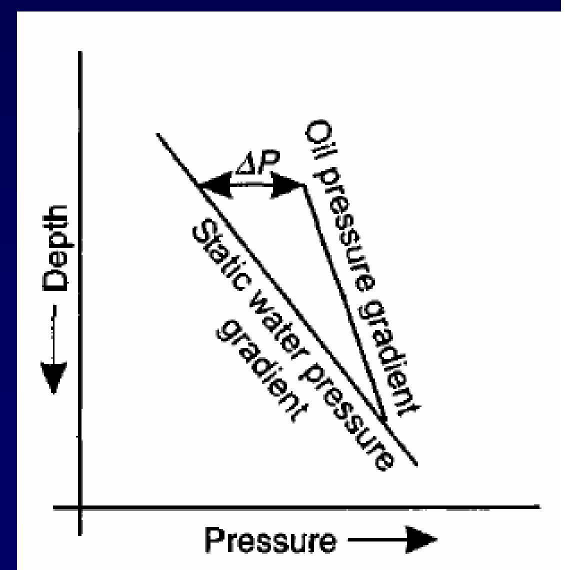
Y_p = height of petroleum column

g = acceleration

ρ_w = subsurface density of water,

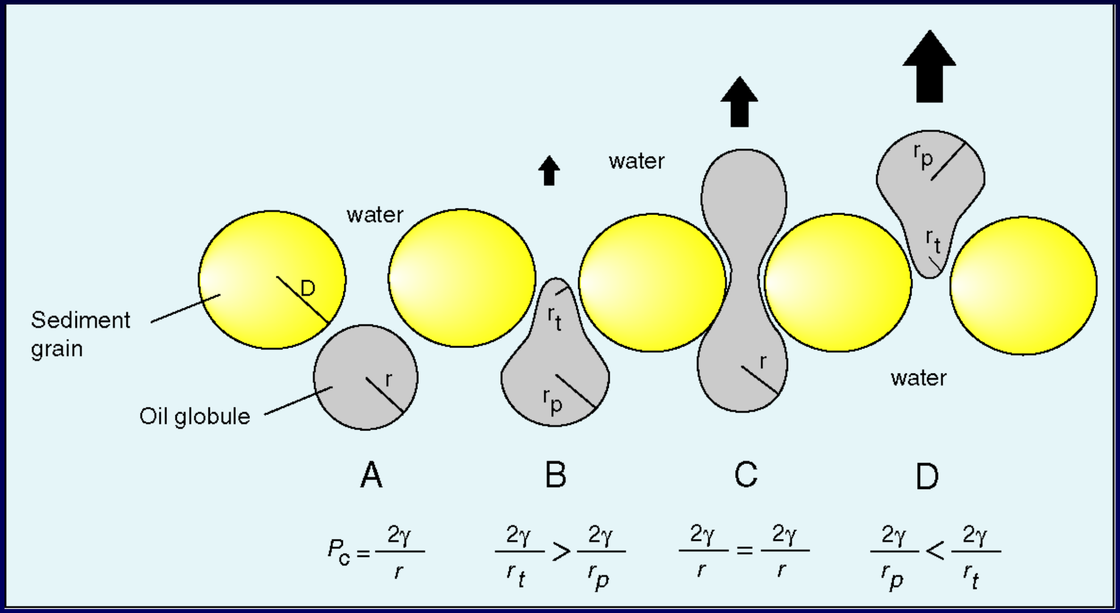
ρ_p = subsurface density





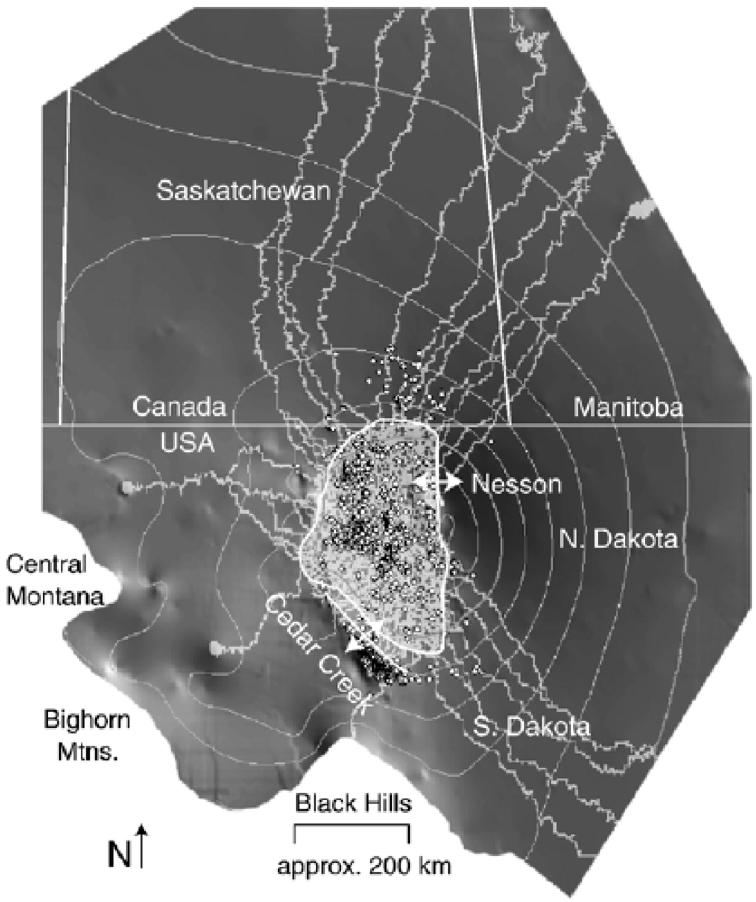
Capillary Pressure

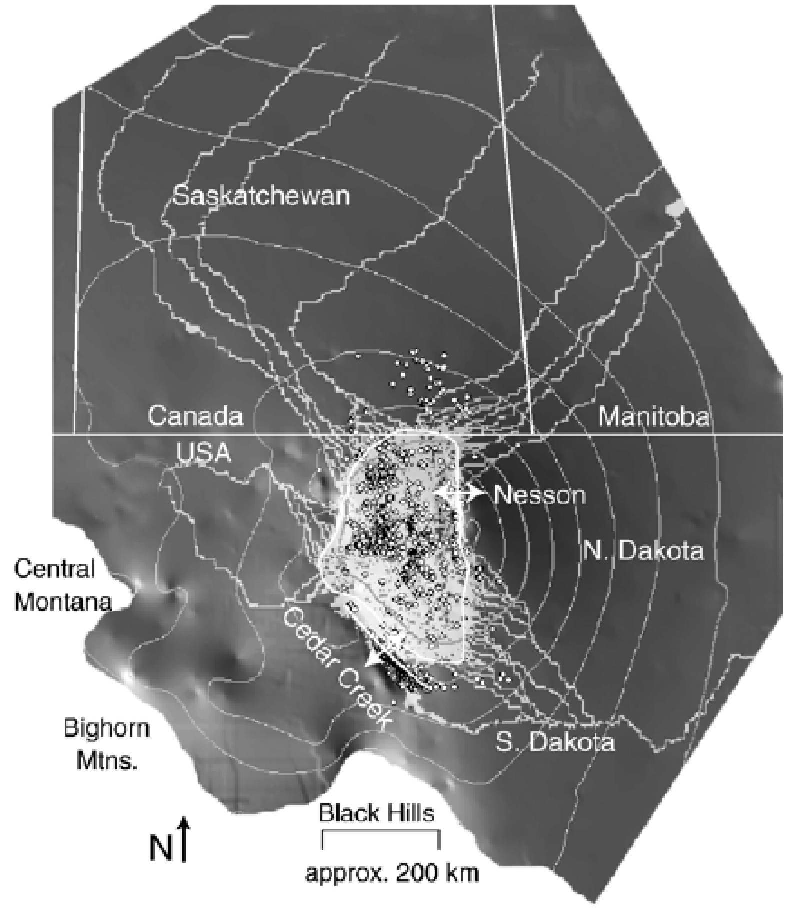
Function of interfacial tension between the immiscible fluids and the pore throat sizes.



Hydrodynamic

Hydrostatic Model | **Hydrodynamic Model**





(Khan et al., 2006)

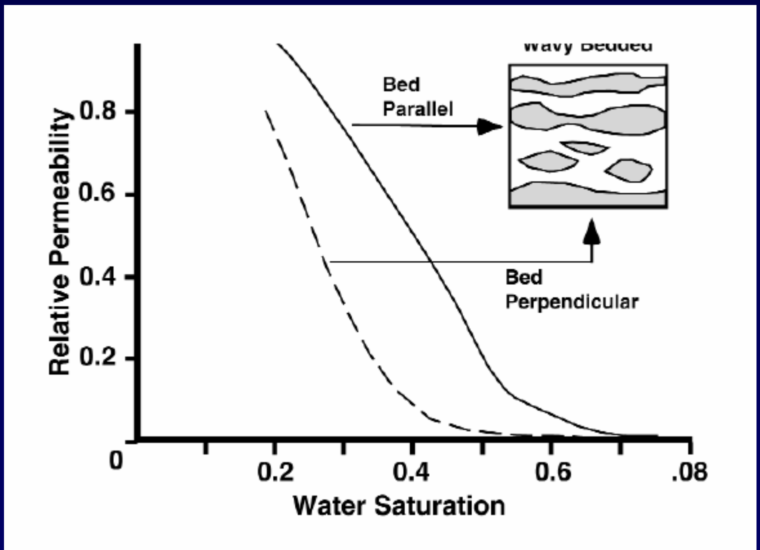
Other factors

Permeability anisotropy

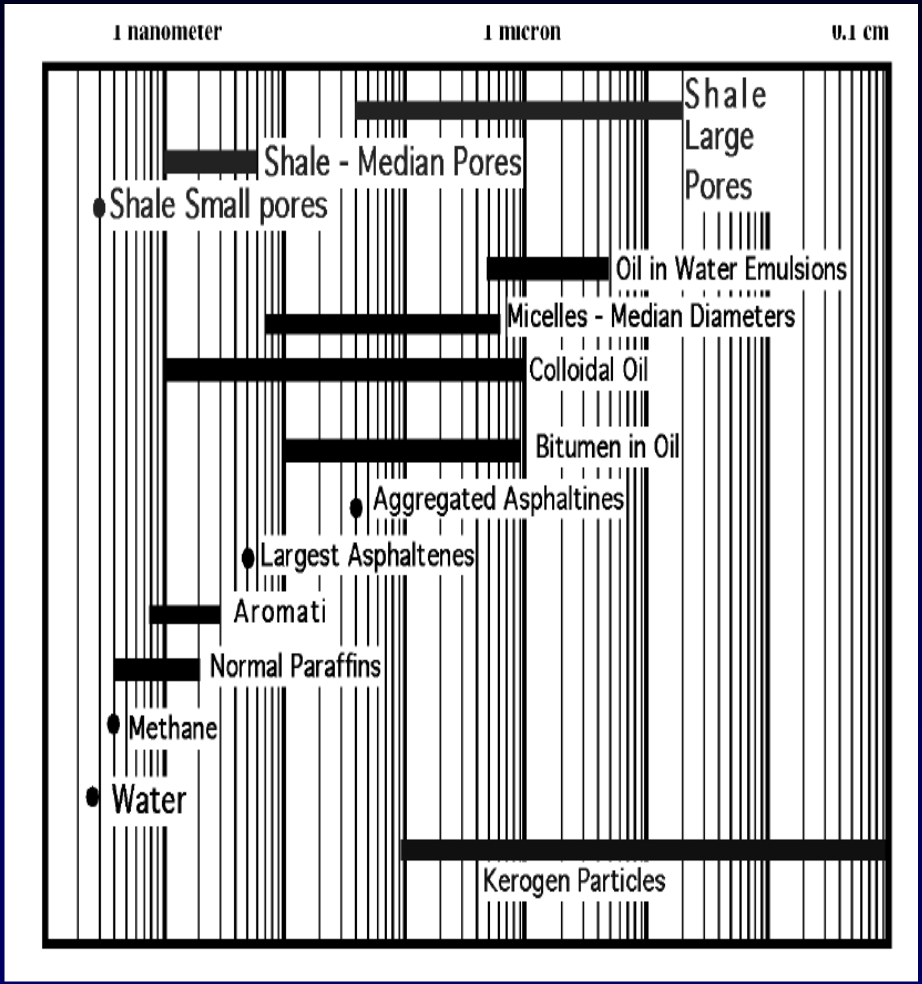
Hydrocarbon molecular size

Adsorption

Temperature (diagenesis, degassing, solubility etc)



(Ringrose & Corbett, 1994)

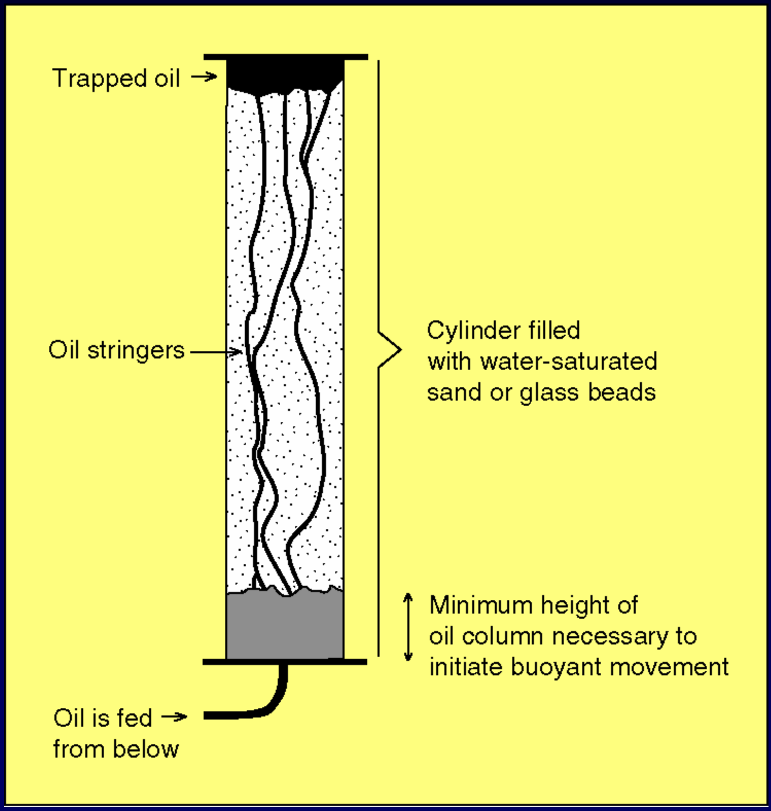


(Momper, 1978)

Secondary Migration

Modeling Options

- Darcy Flow
- Invasion Percolation
- Ray-Tracing



Darcy Flow	Invasion Percolation	Ray-Tracing (Map-based)
Fully coupled processes	Instantaneous migration	Very rapid, instantaneous migration
Takes into account phase changes.	Capillary trapping only	Gravity-driven migration
All type of trapping (capillary, permeability, hydrodynamics etc)	Shorter simulation time	Lateral migration below the seal
Very long simulation time	Allows multiple realization	Neglecting HC phases, pressure gradient etc)
Low resolution grids	Longer migration distance	User imposed barriers
Shorter migration distance	Minimize migration losses	
High hydrocarbon losses		