NORWEGIAN PETROLEUM
DIRECTORATE

BASIN MODELING

the concept
formation synthesis
modeling tools

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Introduction

What is a basin and basin analysis?

Mechanisms of Basin Formation and classification

Types of basin models

Tools : Sequence stratigraphy, backstripping, thermal history

Workflow

Summary

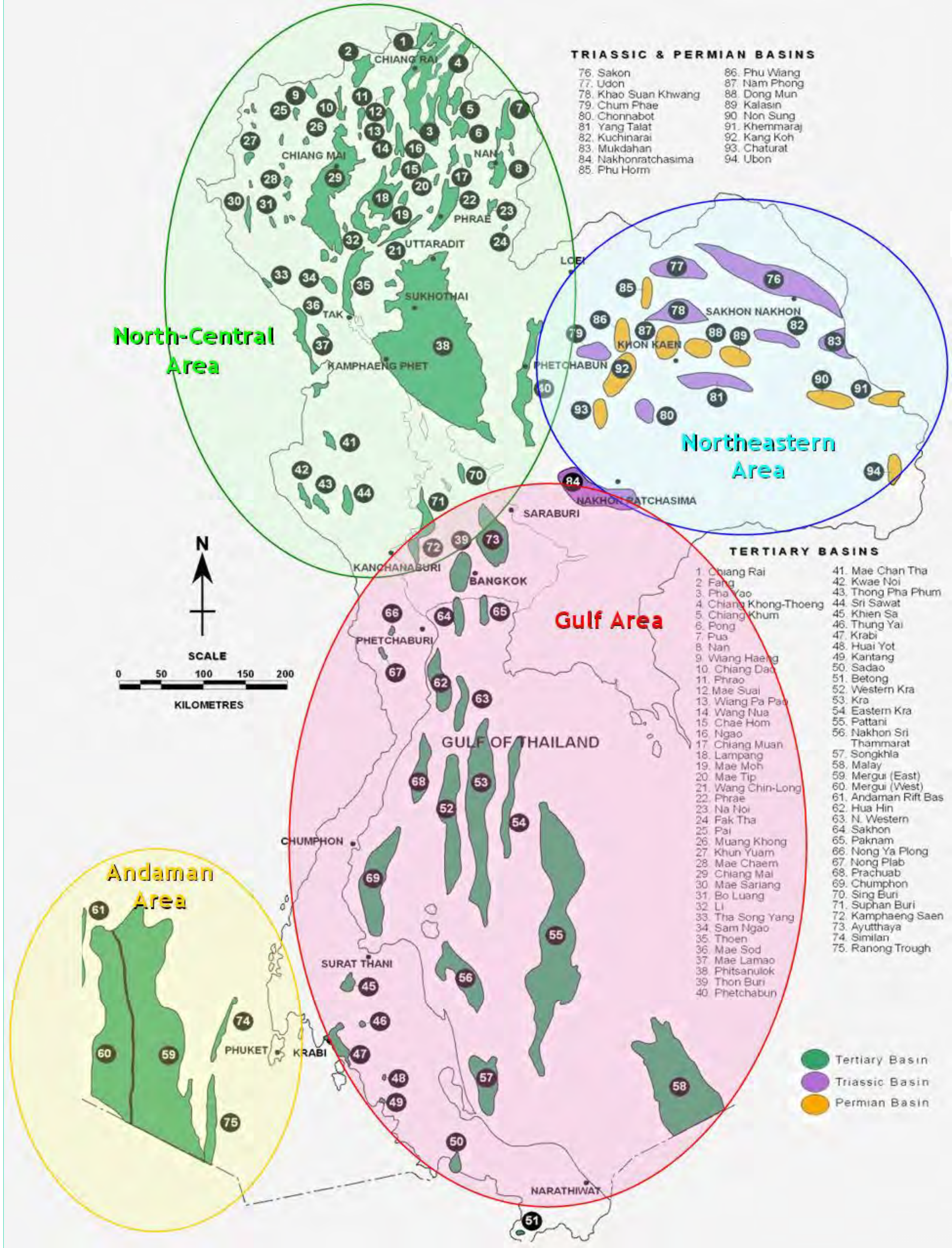
The Basin

Sedimentary basins are regions of the Earth's crust dominated by subsidence and net sedimentation rates. The subsidence provides the depocentres for sediments such as sandstones, mudrocks and limestones to accumulate, in some cases to a thickness >10 km.

Each continent has sedimentary basins, including Antarctica. The deepest basins (>15 km) are found in the southern Caspian Sea and in the western Gulf of Mexico.

Sedimentary rocks are important because they are the "tape recorder" of past climate, sea-level and environmental change.

They are also the world's largest repositories of oil and gas.



Basins of the Southeast Asia

Different ages
Similar tectonics
Same SR and thermal
Accumulation history

Basin modeling

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Definition:

Basin modeling or analysis is a **technique** for understanding physical and chemical processes that cause oil and gas generation in sedimentary basins.

It allows you to reconstruct the **burial and temperature history** of a sedimentary basin through time and to understand source rock maturation and subsequently hydrocarbon expulsion and migration.

Basin modeling

- **Sedimentary basin modeling** is a geological method by which the history of a sedimentary basin is revealed, by analyzing the sediment fill itself.
- Aspects of the sediment; composition, primary structures, and internal architecture, can be synthesized into a history of the basin fill. This can reveal how the basin formed, how sediment was transported or precipitated, and reveal sediment sources.
- From such syntheses models can be developed to explain broad basin formation mechanisms; backarc, forearc, passive margin, epicontinental and extensional basins.
- Sedimentary basin analysis is often conducted through the use of reflection seismology and well data or (analogue) field data, exhumed and dissected by subsequent tectonic events.
- Important tools in sedimentary basin analysis are geological maps, stratigraphy, chronology, and sequence stratigraphy, in which various sedimentary sequences are related to pervasive changes in sea level and sediment supply.

Basin modeling

At the most basic, a basin modeling must assess:

- The burial history of the basin (backstripping).
- Thermal history of the basin (modeling).
- The maturity history of source rock(s).
- Expulsion, migration and trapping of hydrocarbons (and their different phases).

Why basin modeling?

Various factors influence the petroleum system and it is imperative to understand their evolution through time. With this knowledge the burial and thermal histories can be calculated and used to assess **generated and migrated hydrocarbons as well as migration pathways** and reservoir properties.

Basin modeling is a valuable tool in the search for new reservoirs. Also assessment and ranking of undiscovered resources.

With the increasing processing capability of today's PC's and workstations, the road is open for moving basin modeling to where it belongs, to the geologist doing the basin modeling.

What can basin modeling do?

The resulting model is an **interactive tool** that the geologist can use to:

Test impact on prospect charge from changes in various assumptions (as source characteristics), Assess the charge risk associated with each of the various elements of a given petroleum system (e.g., adequate source richness, volume, maturity and timing relative to timing of trap formation).

Estimate volume of petroleum generated from a given volume of source rock(s), volume expelled and lost during migration – and quantity of petroleum delivered to the trap(s).

What can basin analysis do?

Depending on the sophistication of the model (and the data on which the model is based!), the basin model may help the geologist address issues such as:

The timing of hydrocarbon generation relative to the timing a trap formation.

The volumes of hydrocarbons delivered to a trap.

Hydrocarbon type in the trap (liquid vs. gas and their relative proportions).

Physical properties (PVT) of the hydrocarbon charge.

Possible migration paths to the prospect (and migration shadows).

Possible post-charge loss from the trap (seal leakage, tilt and spill, thermal cracking, biodegradation).

What are basins important?

- They are the world’s main source of hydrocarbons.

- Sedimentary basins have records of the Earth’s past environmental changes.

- The main cause of subsidence is sediment loading and thermal contraction in the lithosphere.

- Other processes contribute, such as sediment compaction, salt collapse, and sea-level change (isostatic adjustment).

- Using this and working “backwards” one can deduct sediment input and distribution.

- Overall framework for (semi-)regional understanding of the HC-system.

The concept of basin

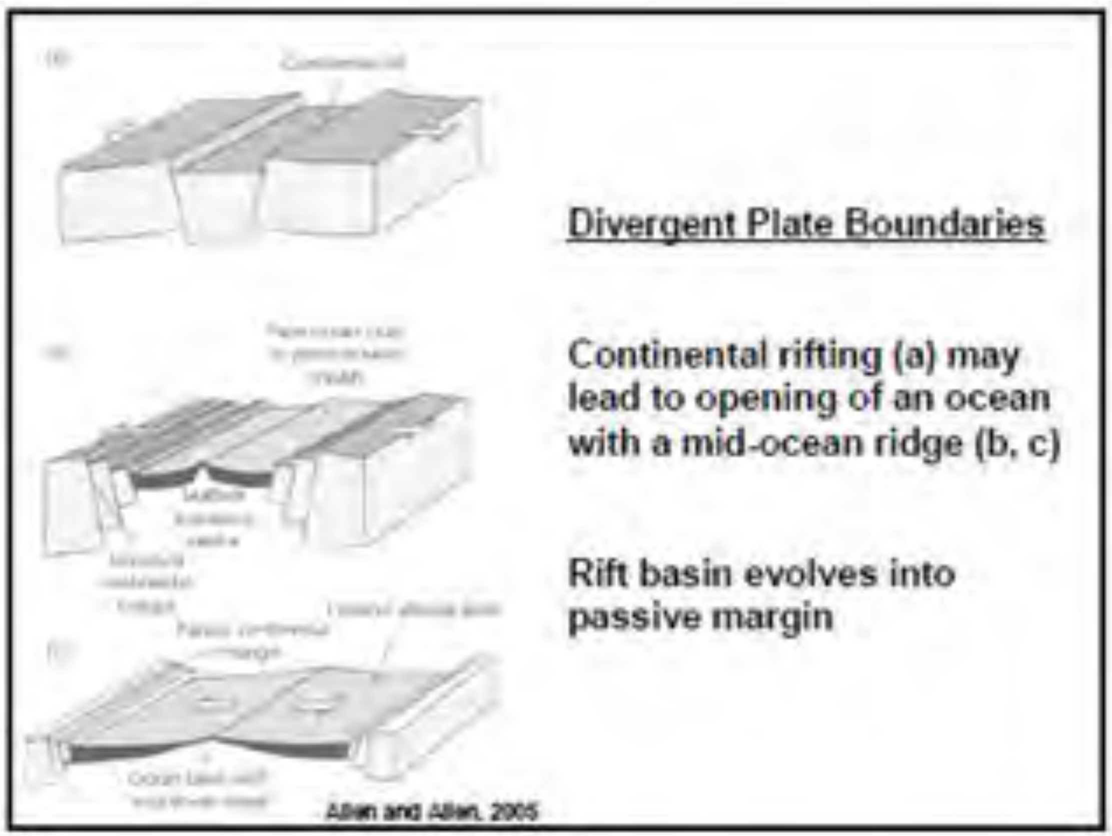
- A basin is large scale features
- Depression filled with sediments
- Often connected to tectonics or crust cooling
- Important play areas for HC
- They are very common – on all continents
- Basins contain geological history
- The deepest basins are associated with plate boundaries (e.g. foreland)

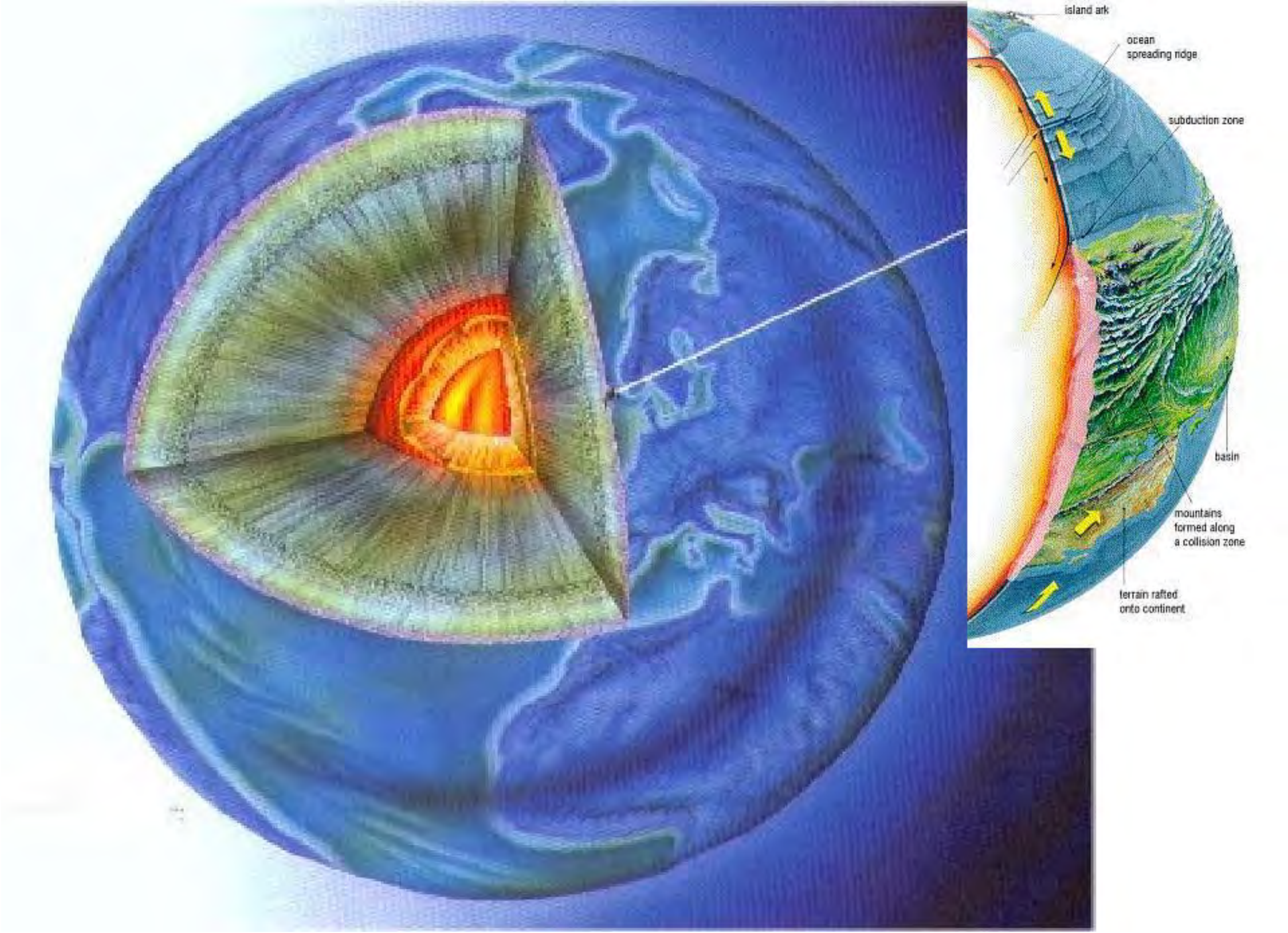
Structural basins are large-scale *structural* formation of rock strata formed by tectonic warping of previously flat lying strata. They are geological depressions - the inverse of domes. Elongated structural basins are known as synclines.

Sedimentary basins have *aggregations of sediment* that filled up a depression or accumulated in the area.

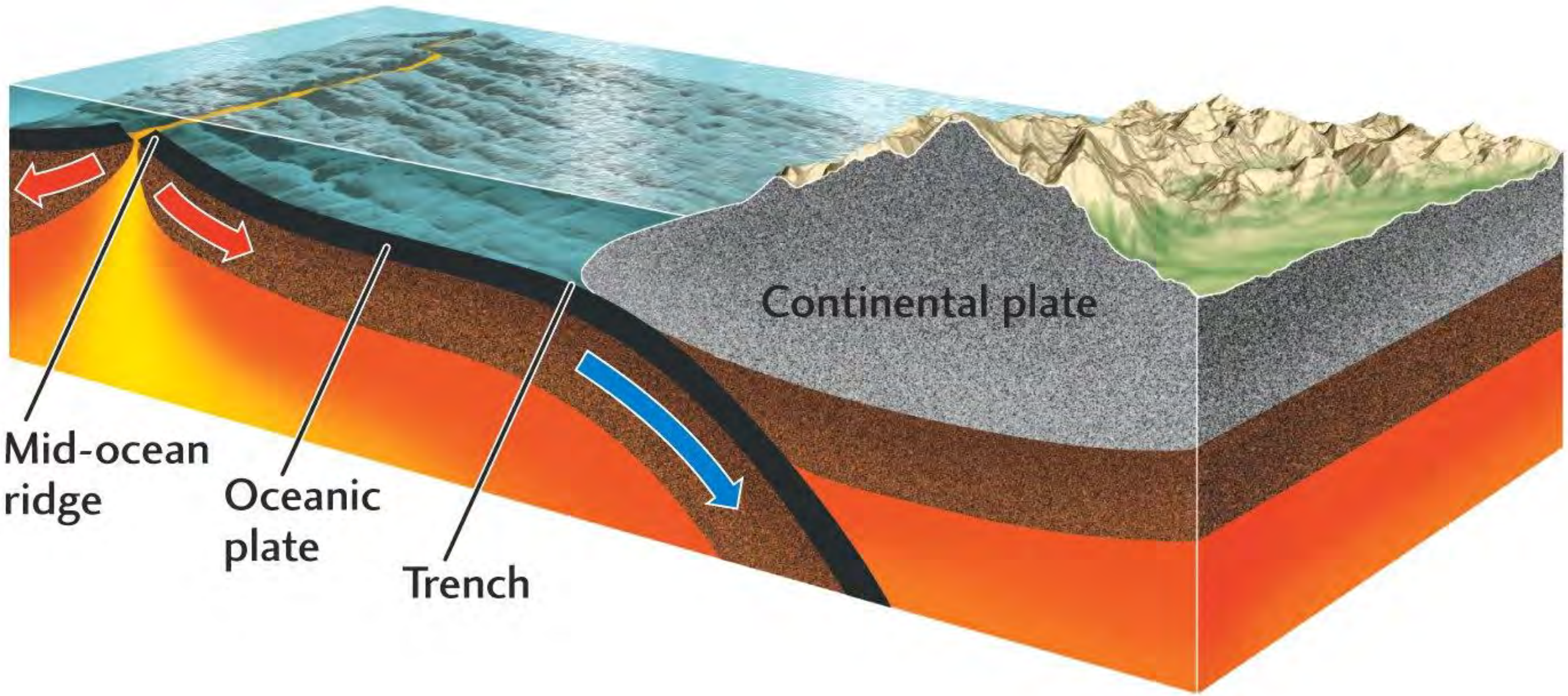
Basins classification and types

There any many types of basins – and mechanisms
Classification based on basin-forming processes
What causes subsidence (and sediment trapping)?
Basins can be related to tectonic setting and plate boundary position

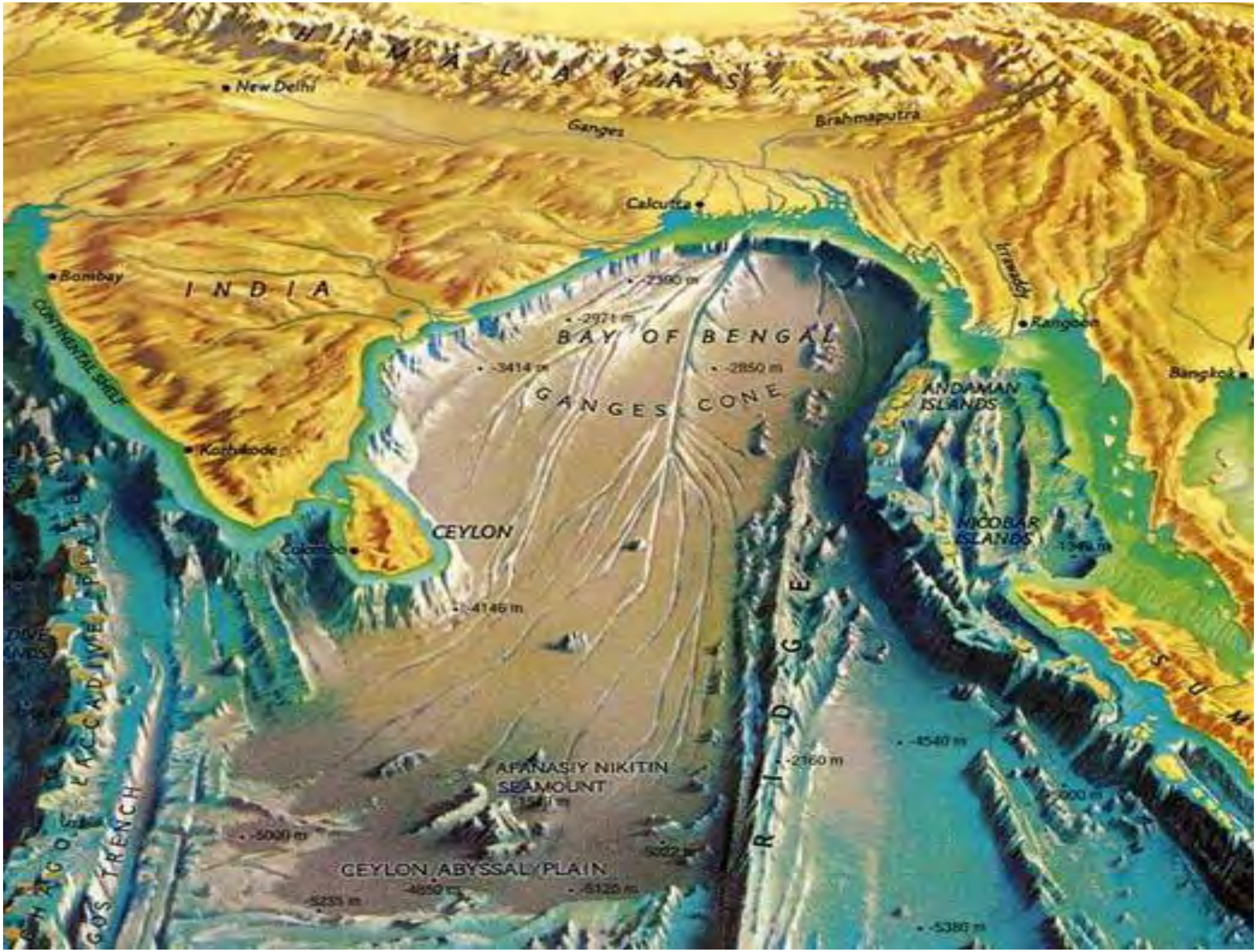



island ark
ocean
spreading ridge
subduction zone
basin
mountains
formed along
a collision zone
terrain rafted
onto continent

Basins classification



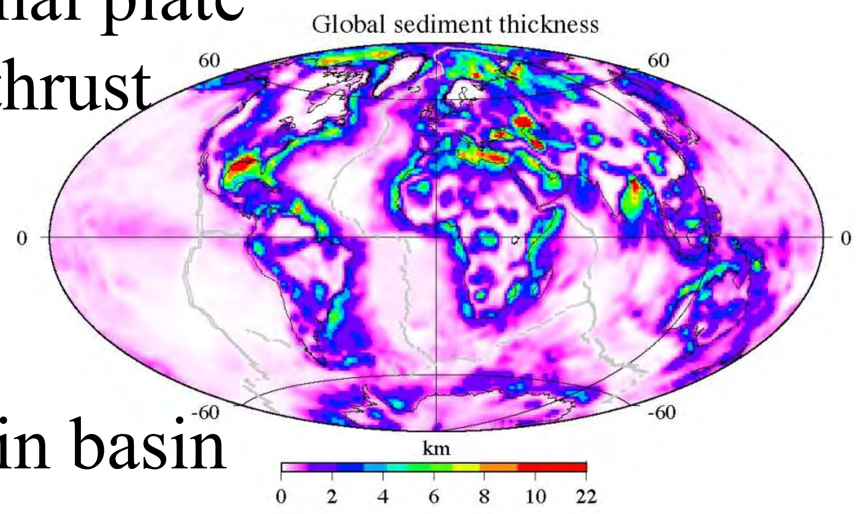
Tectonic developement of continental margin (subduction)


HIMALAYAS
New Delhi
Ganges
Brahmaputra
Calcutta
Bombay
INDIA
CONTINENTAL SHELF
BAY OF BENGAL
GANGES CONE
ANDAMAN ISLANDS
Rangoon
Bangkok
Irrawaddy
CEYLON
Colombo
NICOBAR ISLANDS
RIDGE
APANASIY NIKITIN SEAMOUNT
CEYLON ABYSSAL PLAIN
CHAGOS TRENCH
-2390 m
-2971 m
-3414 m
-2850 m
-4146 m
-4540 m
-2160 m
-5000 m
-5235 m
-4850 m
-5120 m
-5380 m

Basins classification and types

We may divide sedimentary basins into three main types, depending on their plate tectonic setting

Rift-type basins form at extensional plate boundaries, for example, at continental margins.
Foreland-type basins form at compressional plate boundaries in front of migrating fold and thrust belts.
Strike-slip fault settings.



It is now generally recognized that the main basin forming mechanism is **sediment loading**.

Basins classification - Rift Basins

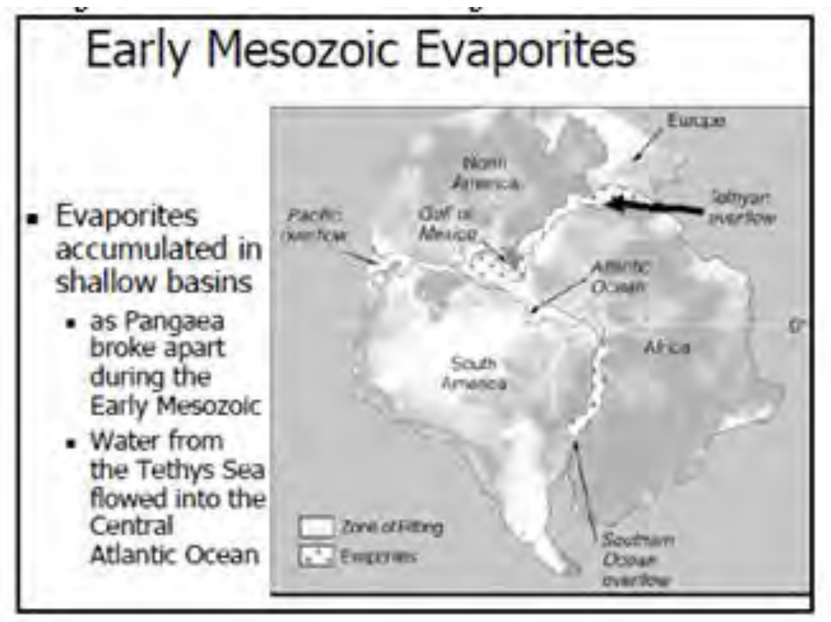
Sedimentary fill commonly consist of continental deposits

Fluvial, lacustrine, alluvial fans, etc

In hot and dry areas, evaporites may form (invation of sea)

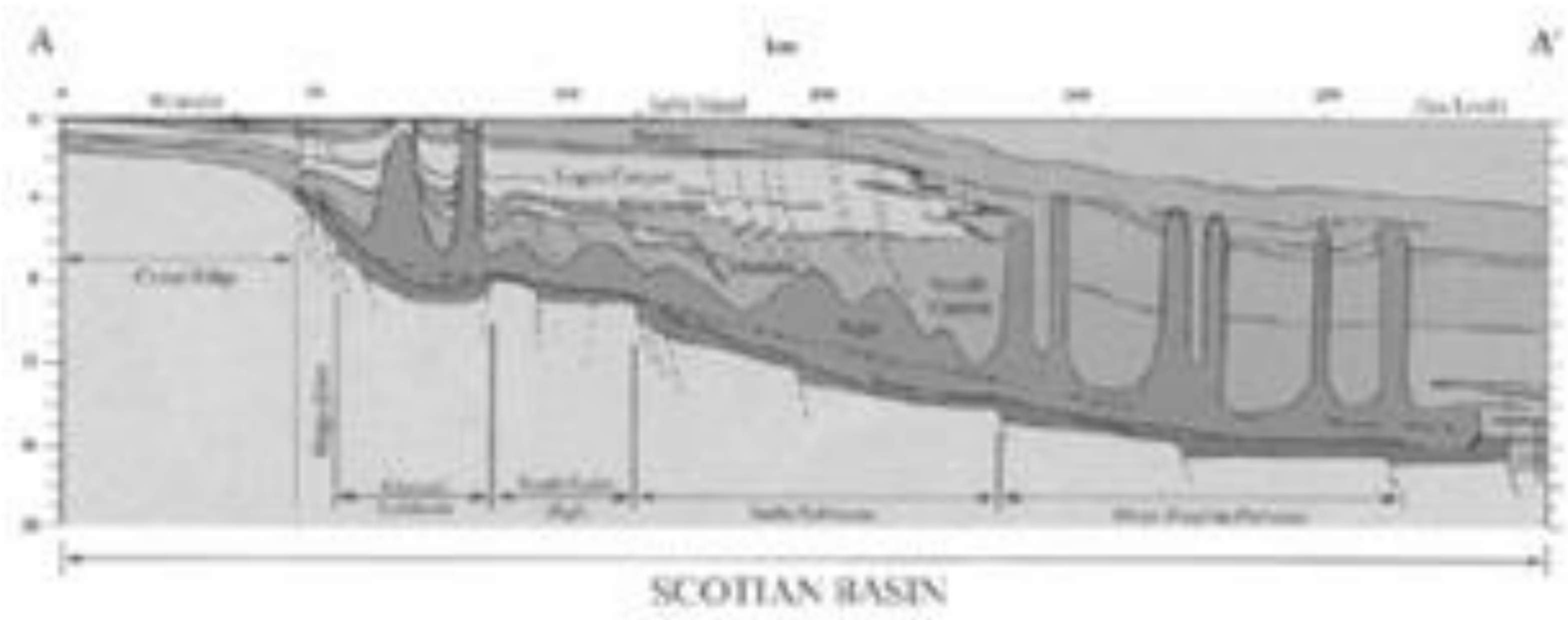
May contain volcanics or assosiated intrusions

Backstripping studies of data from stratigraphic test wells in rift-type basins suggest that the main cause of their subsidence is sediment loading and thermal contraction following heating and thinning of the lithosphere at the time of rifting. Other processes contribute (e.g. sediment compaction, salt collapse, and sea-level change) but their contribution to the subsidence is small compared to that of the two main factors.



Basins classification - Passive margins

Developed on the continental crust
Long stretcing distances: 50-500 km
Overlaid by seaward thickening sediments (shallow marine)
Gravity driven deformation (e.g. deltas)
Faults are listric, growth faults, salt tectonic/&diapirs



Basins classification - Foreland arc

Dominated by sediments from arc:

immature clastics or continental back-arc sediments

Deep-sea trench may scrape off sediments from subducting plate

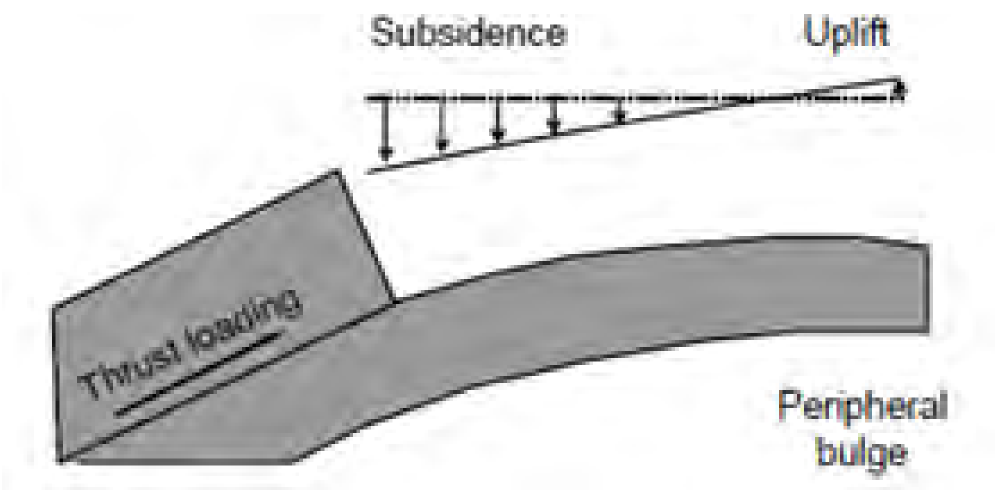
("melange" or mixed rock types)

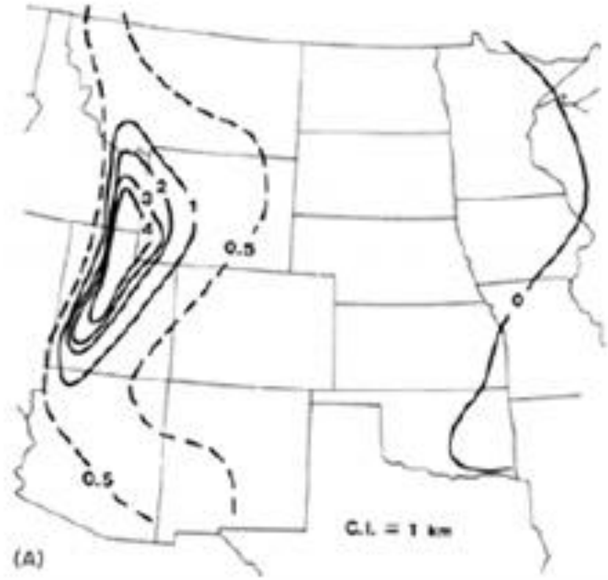
Crustal loading cause subsidence

Slow subsidence early on and a rapid subsidence later on

due to thrust and fold load.

Subsidence rate greates adjacent to thrust loading





Basins classification - intracratonic basins

Dominated by sediments from arc: immature clastics or
continental back-arc sediments

Semi-circular shape

Within interior continent (stable craton) away from plate boundaries

Terrestrial or marine sediment fill

Carbonates, evaporites, clastics,(eolian)

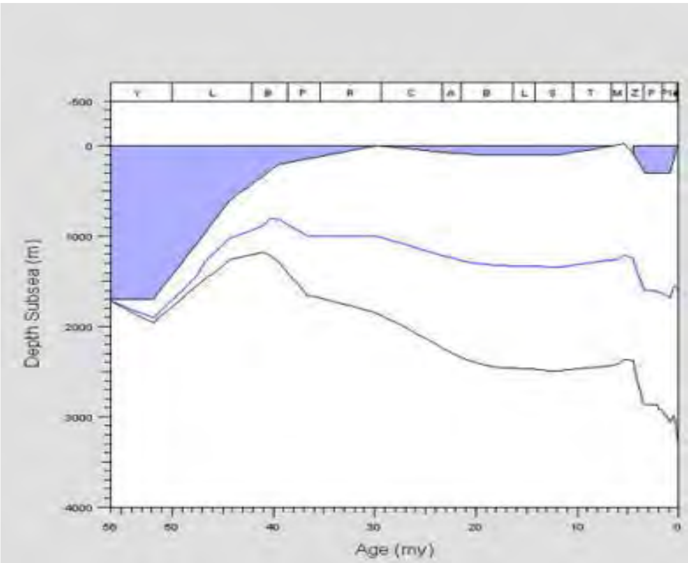
Summary

Sedimentary basins develope as result of relative crustal subsidense.
This may be due to isostacy or sediment loading.
Found in many different tectonic settings (opening/closing of basins)
Act as sediment trap
Passive margins subside due to cooling –sediments increase seawards
Uplift (e.g. thrusting) give variatons in sediments (highland erosion)
Foreland basins subside due to loading.
Intracratonic away from plate margins

Basins may have complex history –
also pseudocyclisity not related to eustatic changes (fluvial deposits).

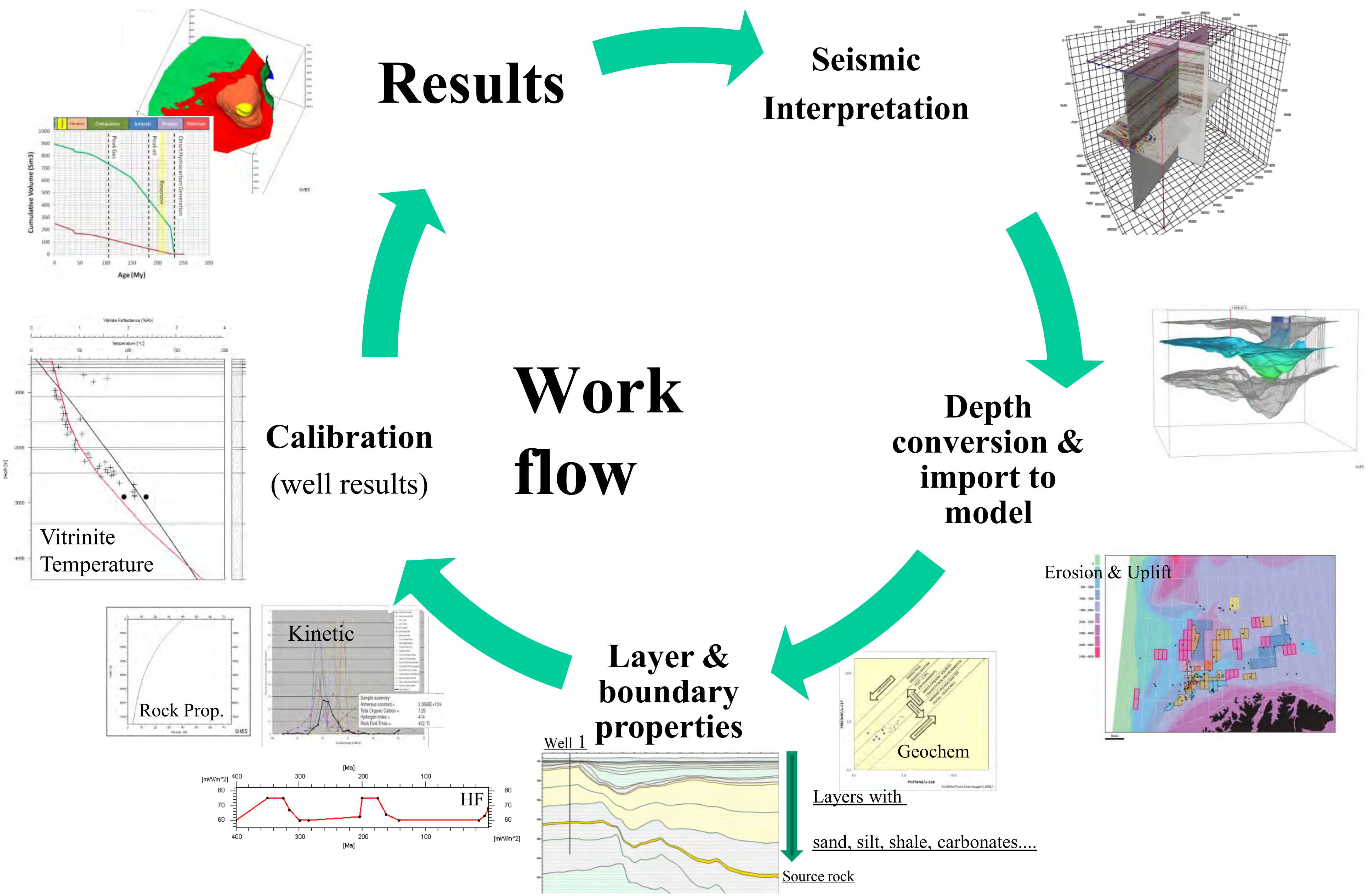
Basin analysis - workflow

Geological data such as maps, lithology, sedimentological history, paleodates
Knowledge of the petroleum system
Building of a conceptual model and calibrate with real data (wells, analogues)
Geological model and development history (backstripping)
Knowledge of the source rock (type, pyrolysis, geochemical, phase shift)
Thermal history and modeling of heat flow (1D)
Depth conversion of seismic (lines)
Modelling of the fluid flow, phase and loss/fill (2D, 3D)



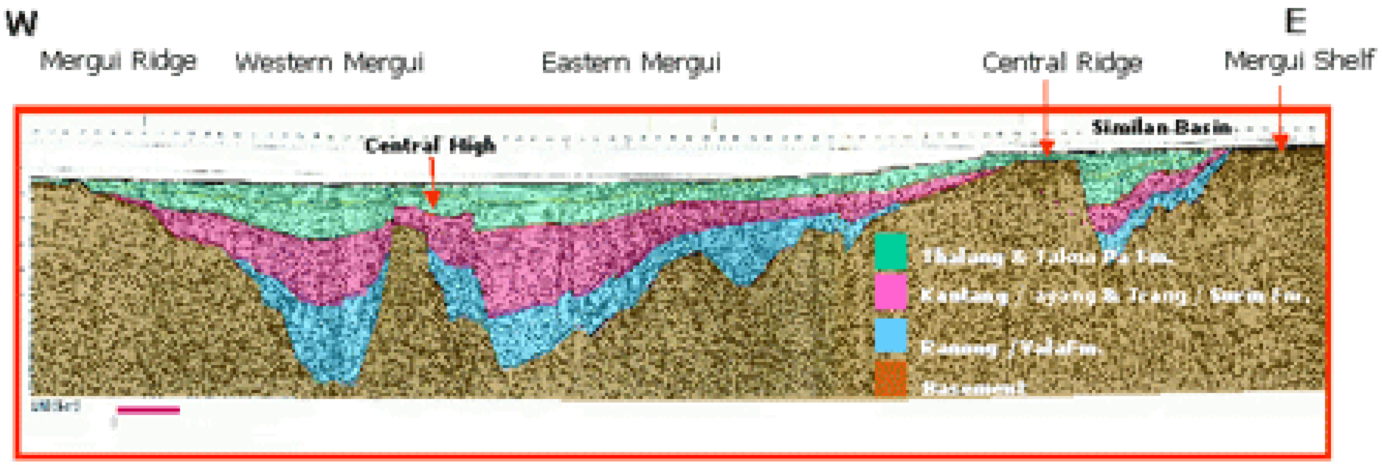
Geohistory diagram of a well

Basin analysis - workflow



Modelling requirements

- Elements of the Petroleum system must be ”known”
- Build a Conceptual model
- Calibrate above model with real data (physical, chemical, thermal, wells)
- Modelling of the heat flow
- Understanding of the source rock type and kinetics
- Modelling of the fluid flow



Types of models

Either 1D, 2D, or 3D basin modeling (basin modelling) may be performed, depending on data available, project goals, time and funding.

Traditionally, basin modeling has been used by the oil and gas industry to study the physical and thermal histories of basins. The models lead to an estimation of the timing of hydrocarbon generation and expulsion.
In recent years, however, basin modeling has expanded to include evaluation of secondary migration and trapping of hydrocarbons within basins.

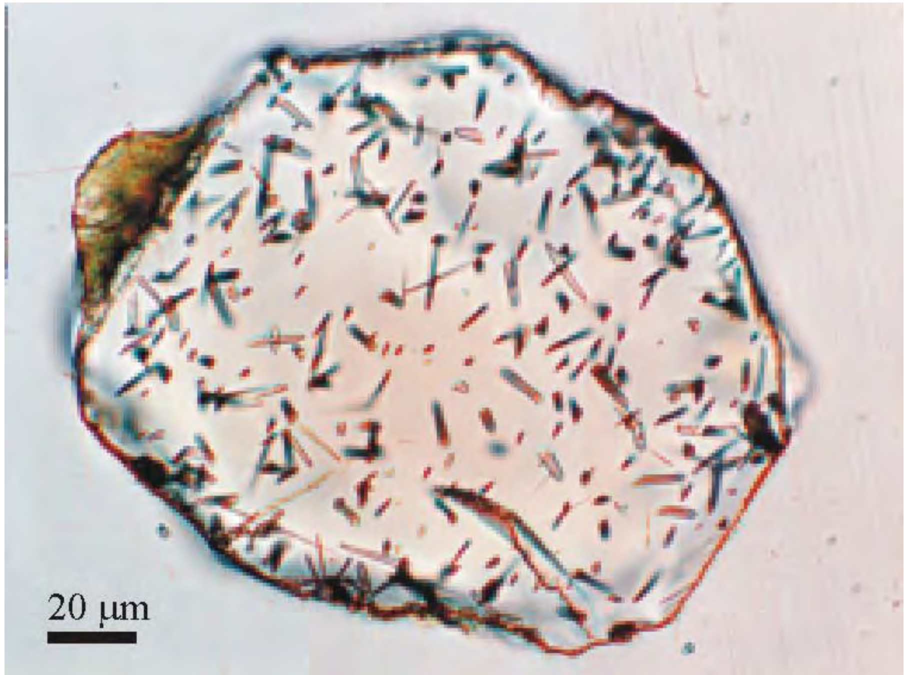
1D modelling: model building, burial history, heat flow history, temperature calibration,
development of source rock maturity, sensitivity analysis.
Gives timing of HC-generation and type of products generated.

2D & 3D modelling: model building, model calibration, hydrocarbon migration.
Give petreolum system information: migration and trapping.

2½D modelling: drainage area analysis, closure size and identification, fill and spill history.

”Real data”

Analogues from onshore or other places
Geophysical data: seismic, gravmag
Well log data
Borehole samples



Reservoir

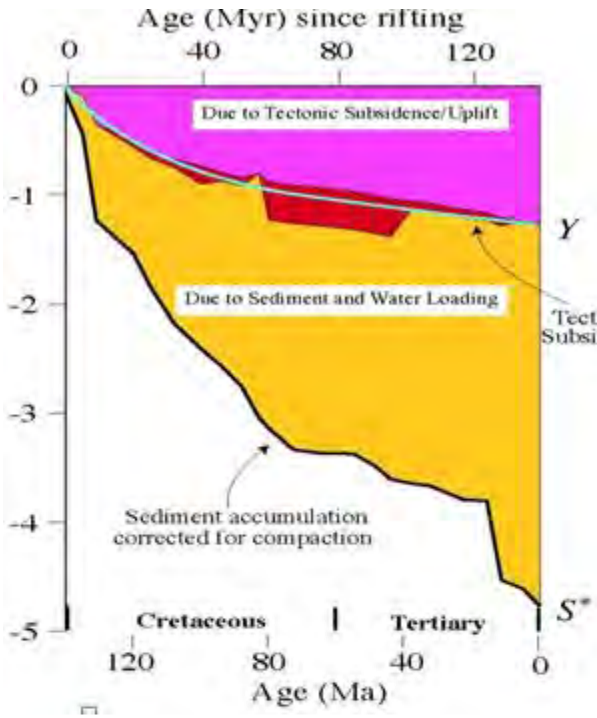
Reservoir

Sediment thickness

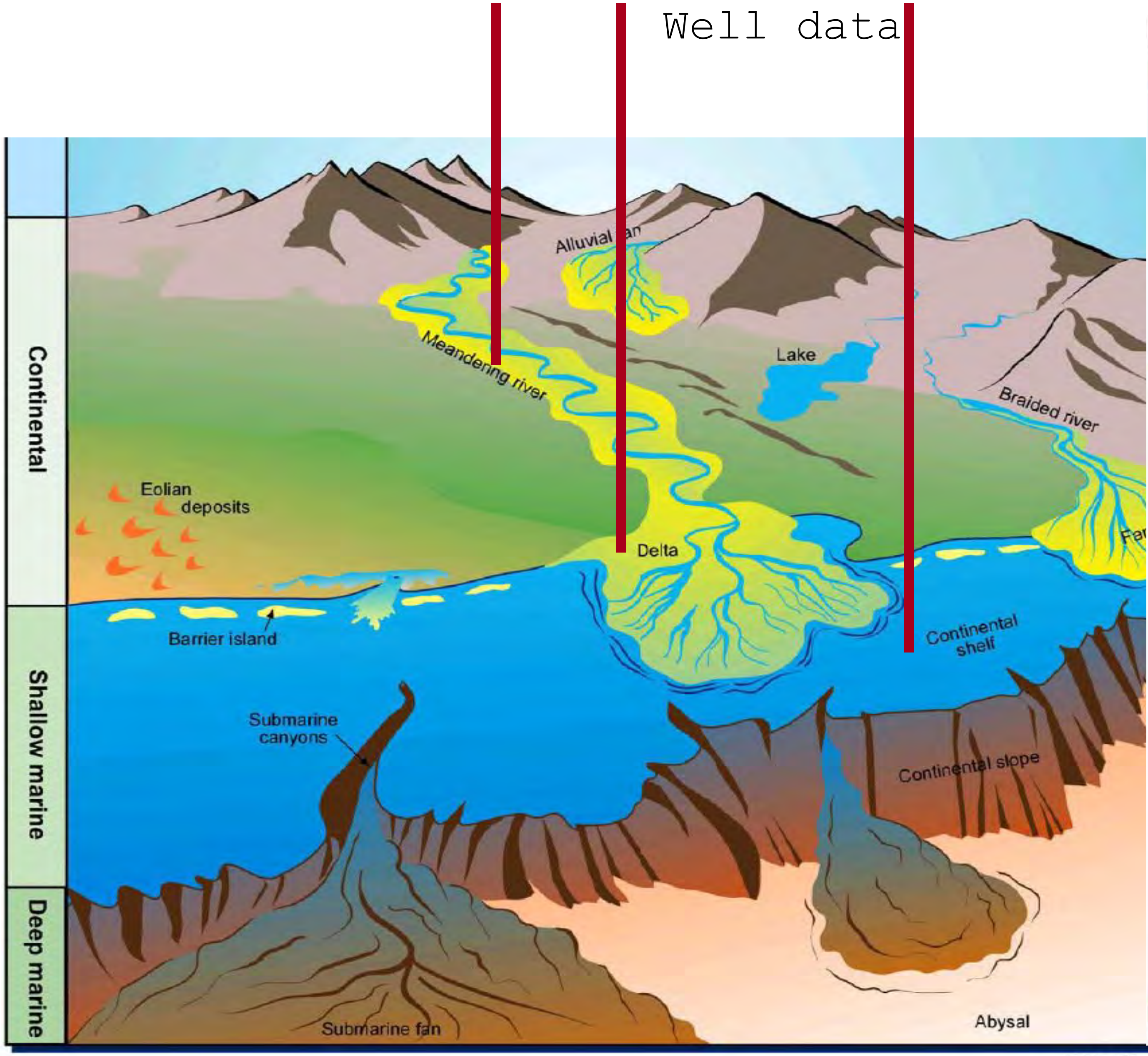
The thickness of sediment that can accumulate due to loading depends on density, but it is approximately 2.5 times the water depth that is available.

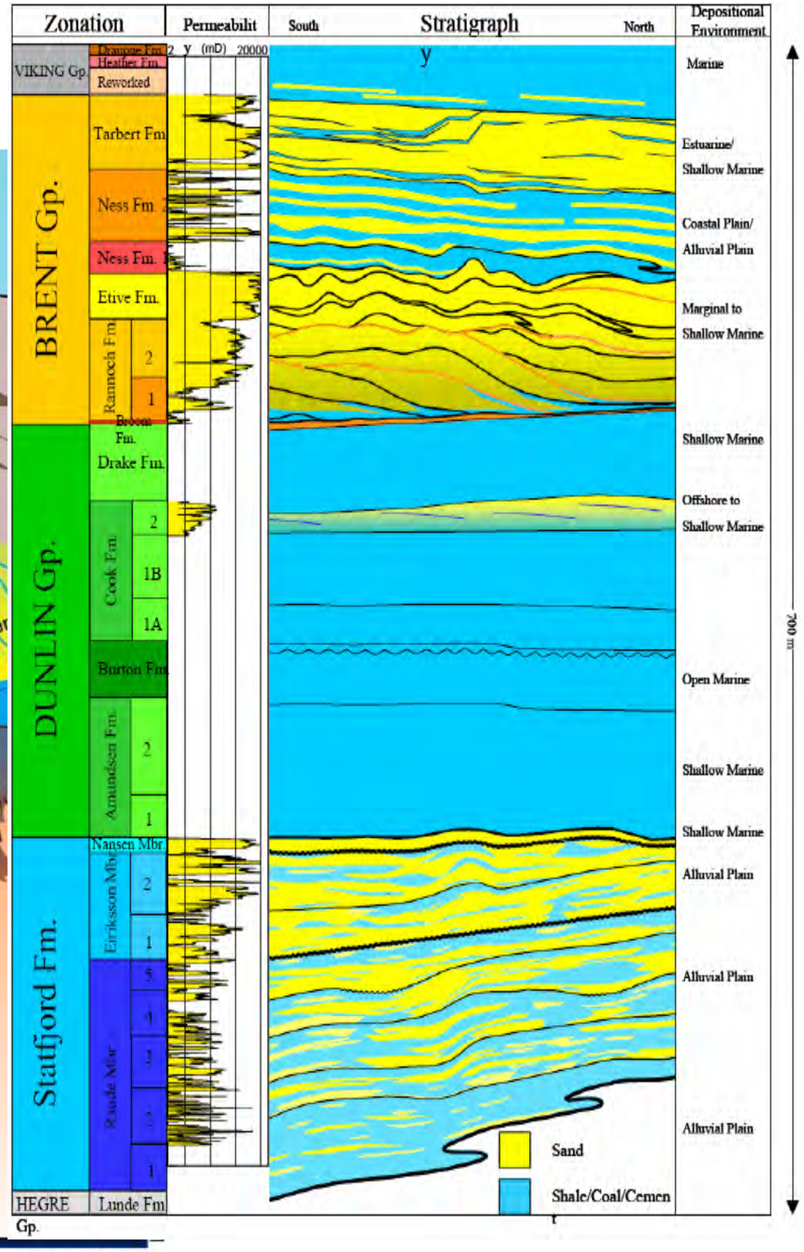
Therefore, if a 6 km deep water basin (e.g. the present-day Phillipine Sea basin) is rapidly infilled by sediment then the *total* thickness of sediment that could accumulate would be 2.5 x 6.0 = 15 km.

Such a model implies a single shallowing upward sequence such that the early sediments would be deposited in deep-water while the later sediments would be deposited in shallow-water.



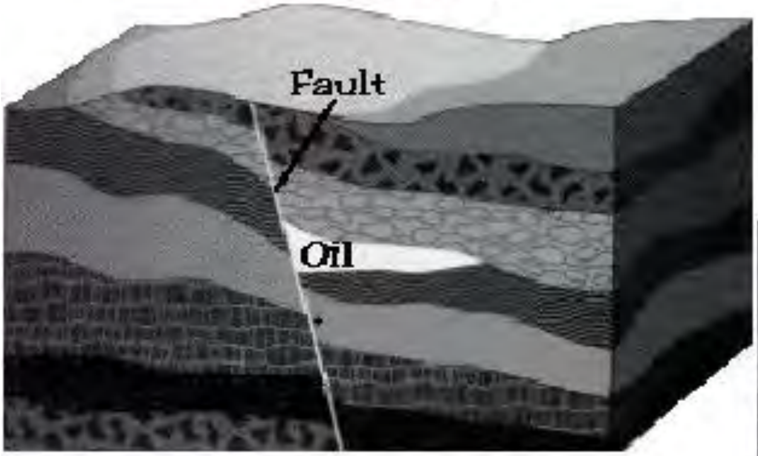
Geological model



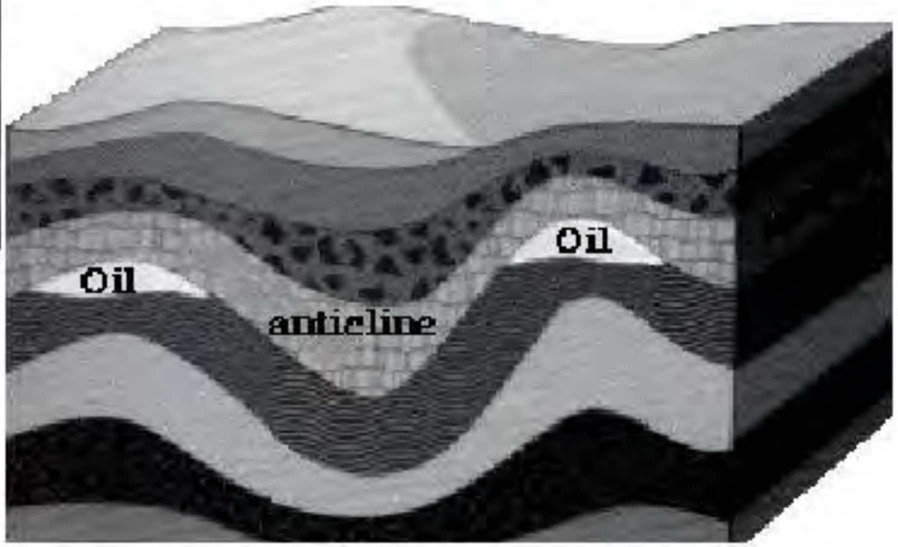


(After Bjørlykke, 1984)

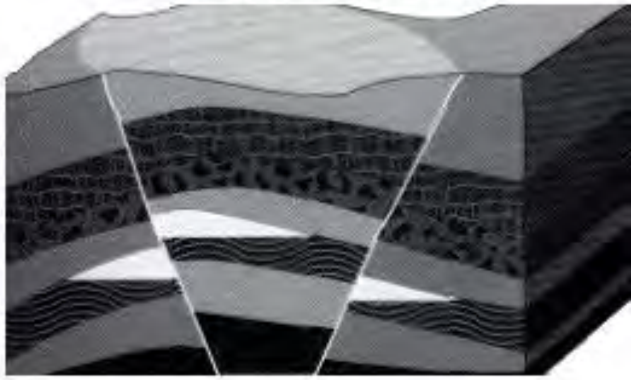
Fault Trap



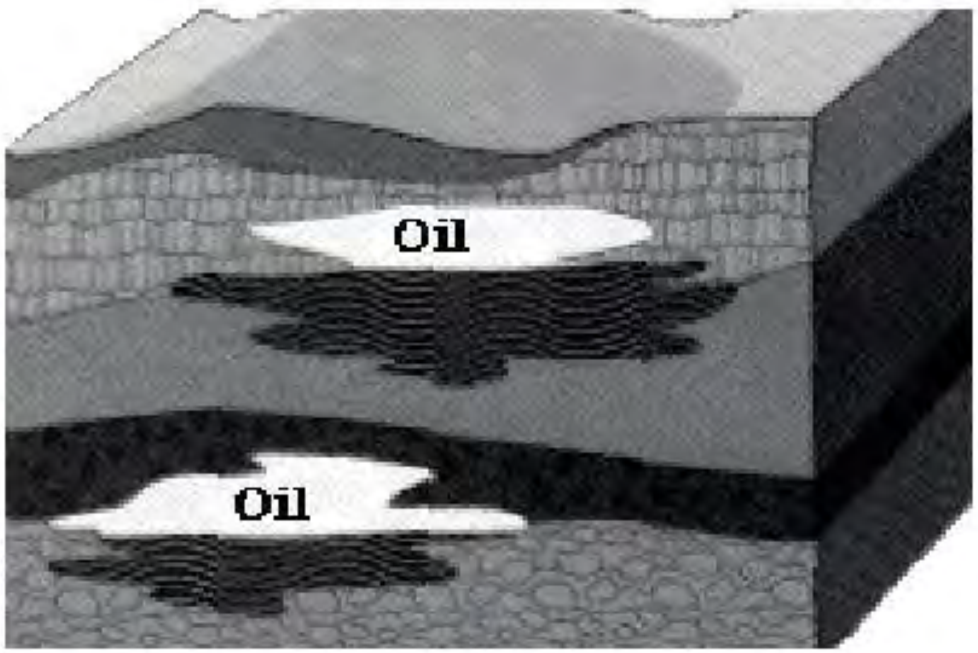
Anticlinal Trap



Combination Trap
Faulted anticline

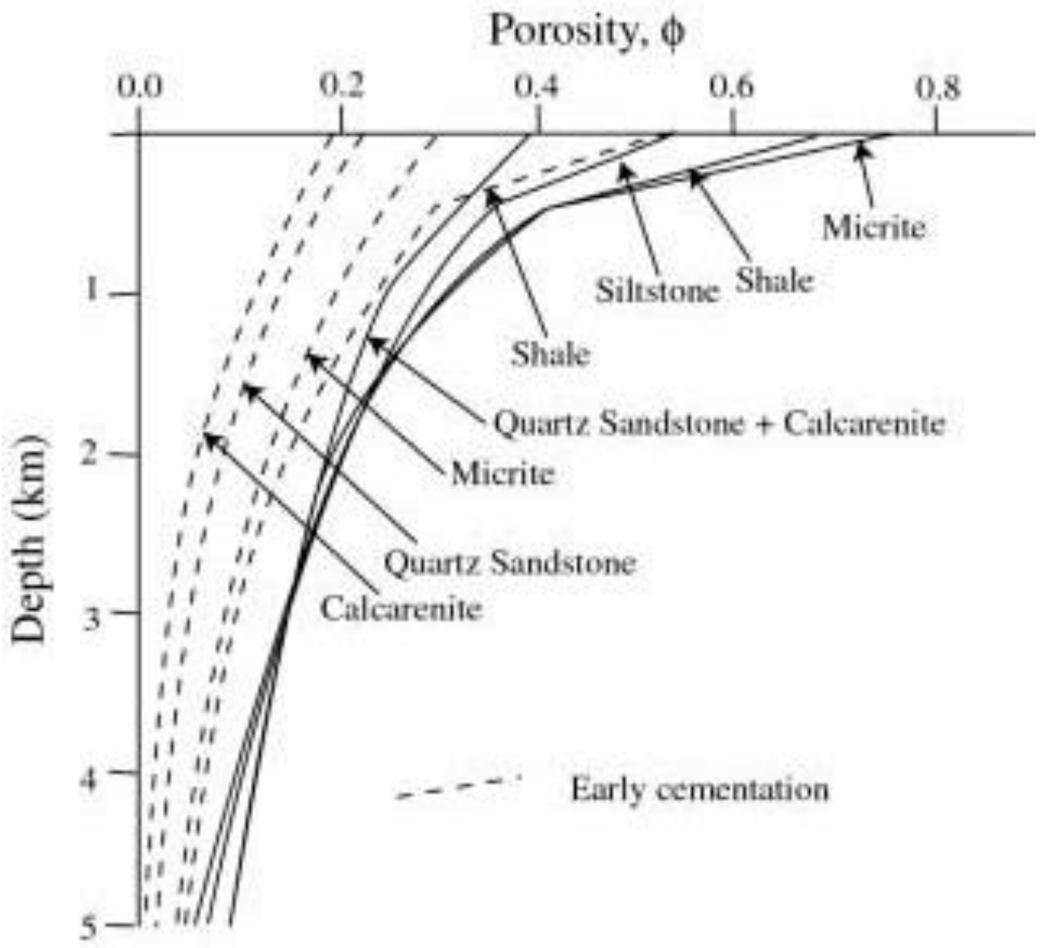


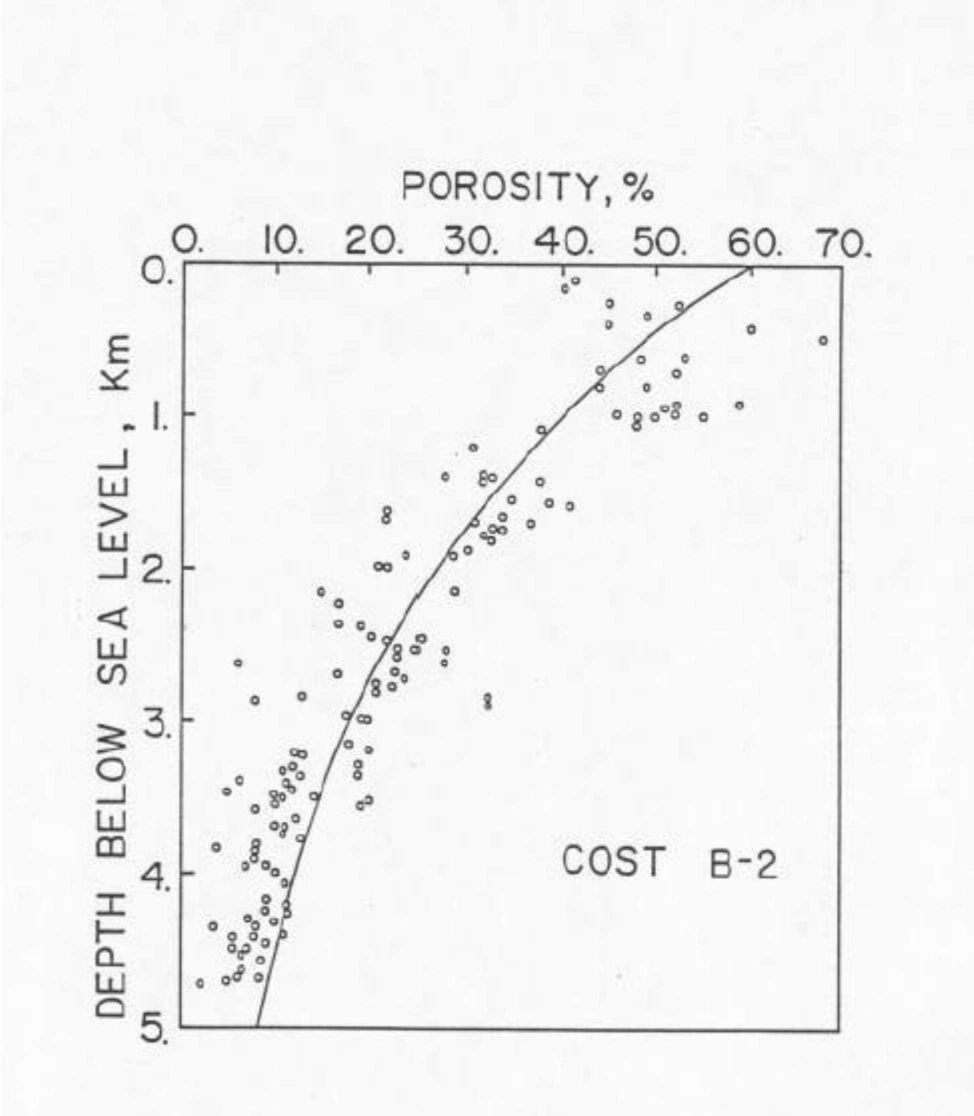
Stratigraphic Trap



Stratigraphic Trap

Porosity vs burial depth





Back-stripping

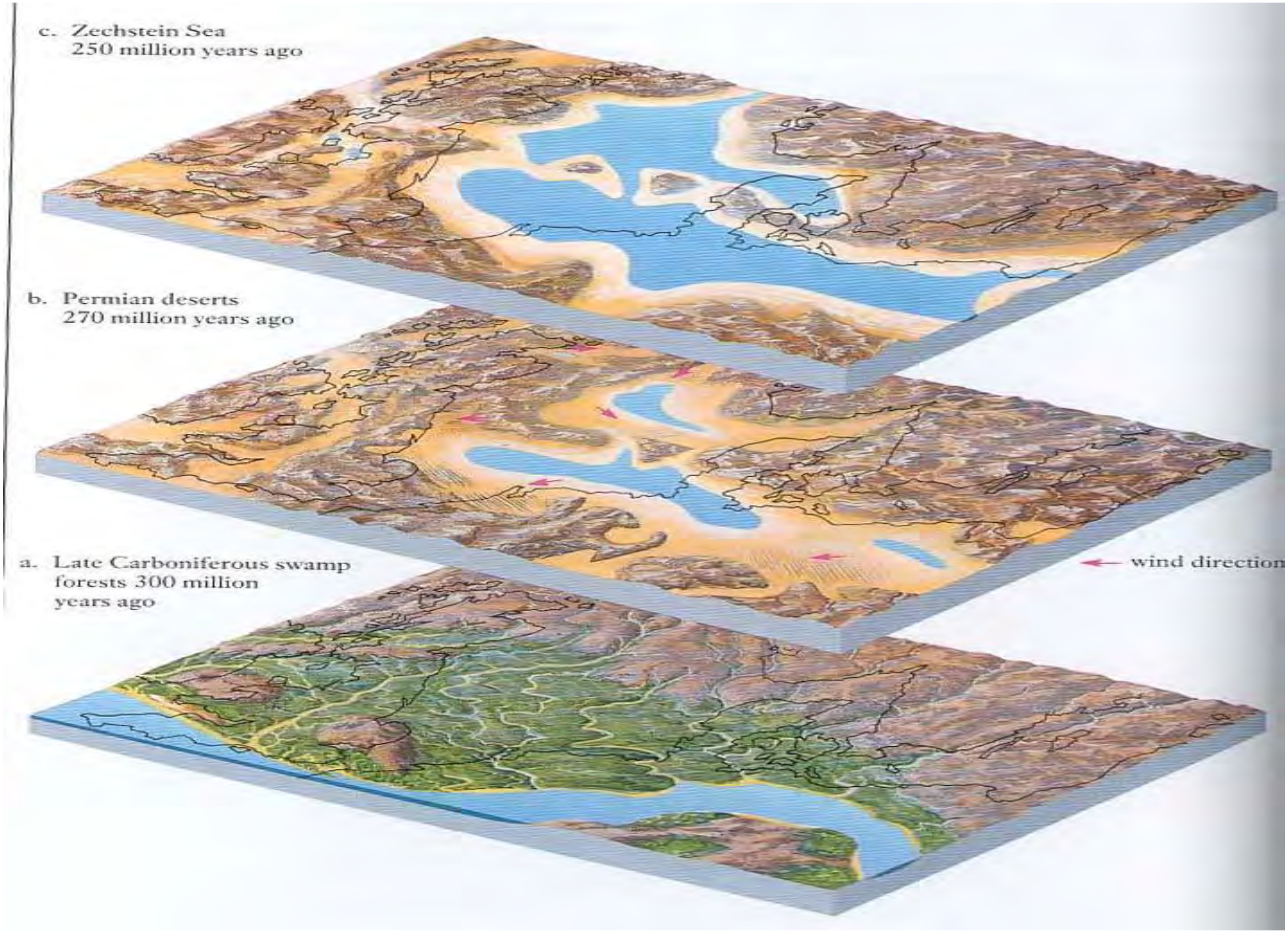
Back-stripping
A geophysical analysis technique used on sedimentary rock sequences to isolate factors which contribute to basin formation/filling **other** than sediment loading.

Sucessive layers of sedimentary basin fill are "stripped off" the total stratigraphic load during analysis of that basin's history. By isolating the isochronous packages one-by-one, these can be "peeled off" or backstripped. The lower bounding surface rotated upward to a datum.

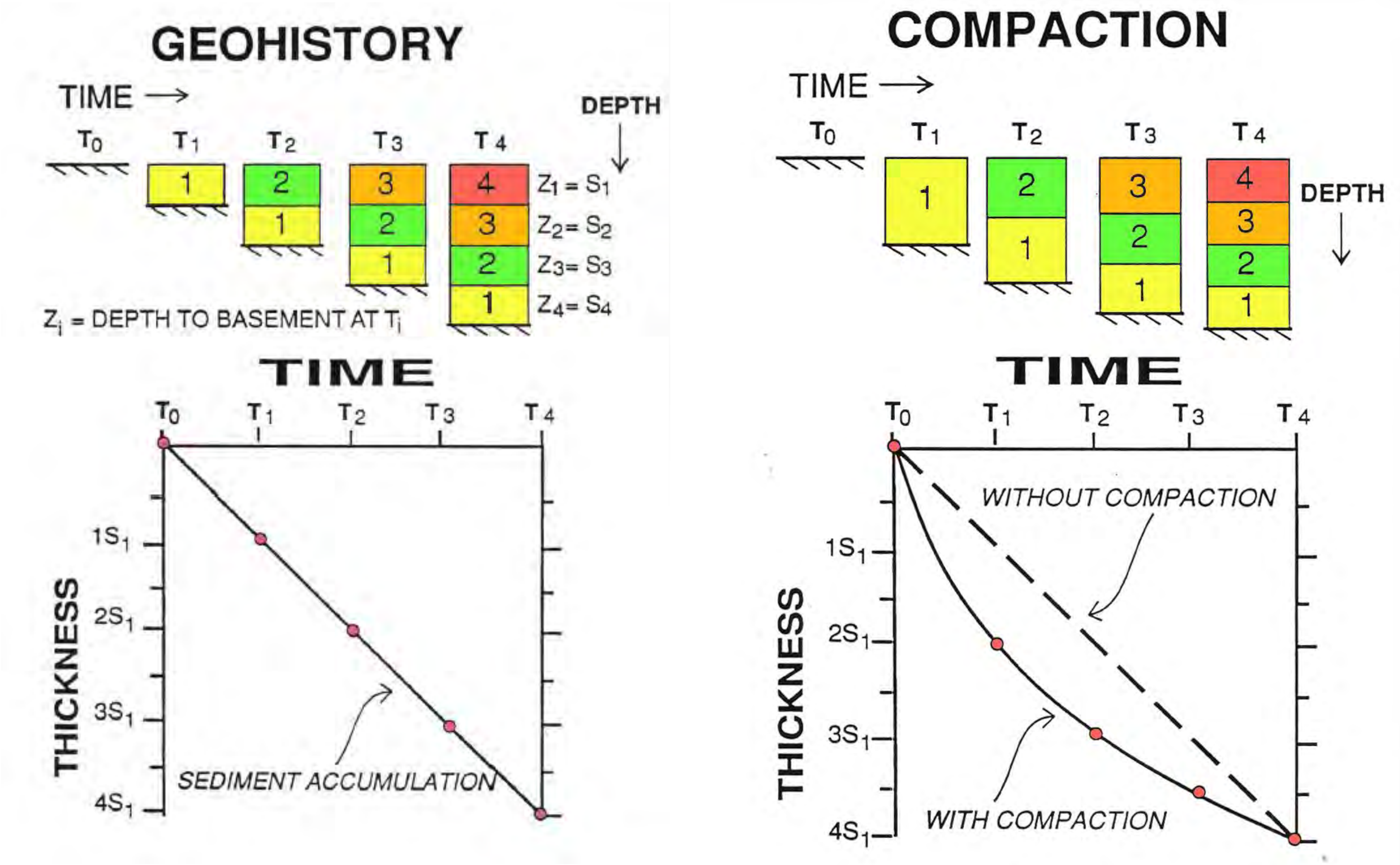
Backstripping uses biostratigraphic, porosity vs. depth, and paleoenvironment data in deep wells to correct the stratigraphic record for the effects of sediment and water loading and obtain the depth that "basement" would be in the absence of these loads. We refer to this depth as the **tectonic subsidence and uplift**. By successively backstripping isochrons, the basin's deepening history can be plotted in reverse, leading to clues as to its tectonic or isostatic origin.

Further sophistication may be performed by using decompaction of the remaining sequence following each stage of the back-stripping. This takes into account the compaction factor caused by loading of later layers, and allows better estimation of depositional thickness of the remaining layers.

Back-stripping

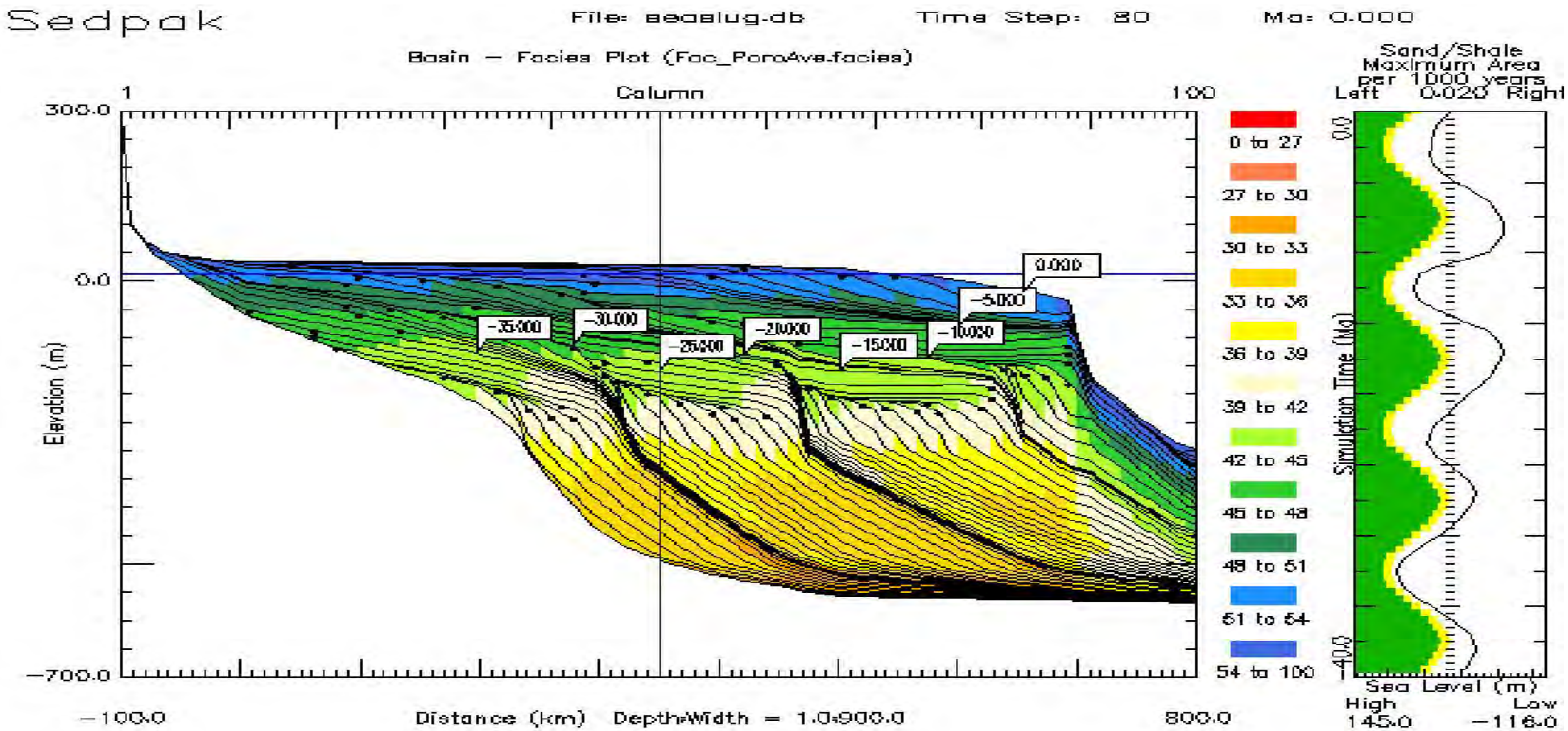


Backstripping – compaction factor

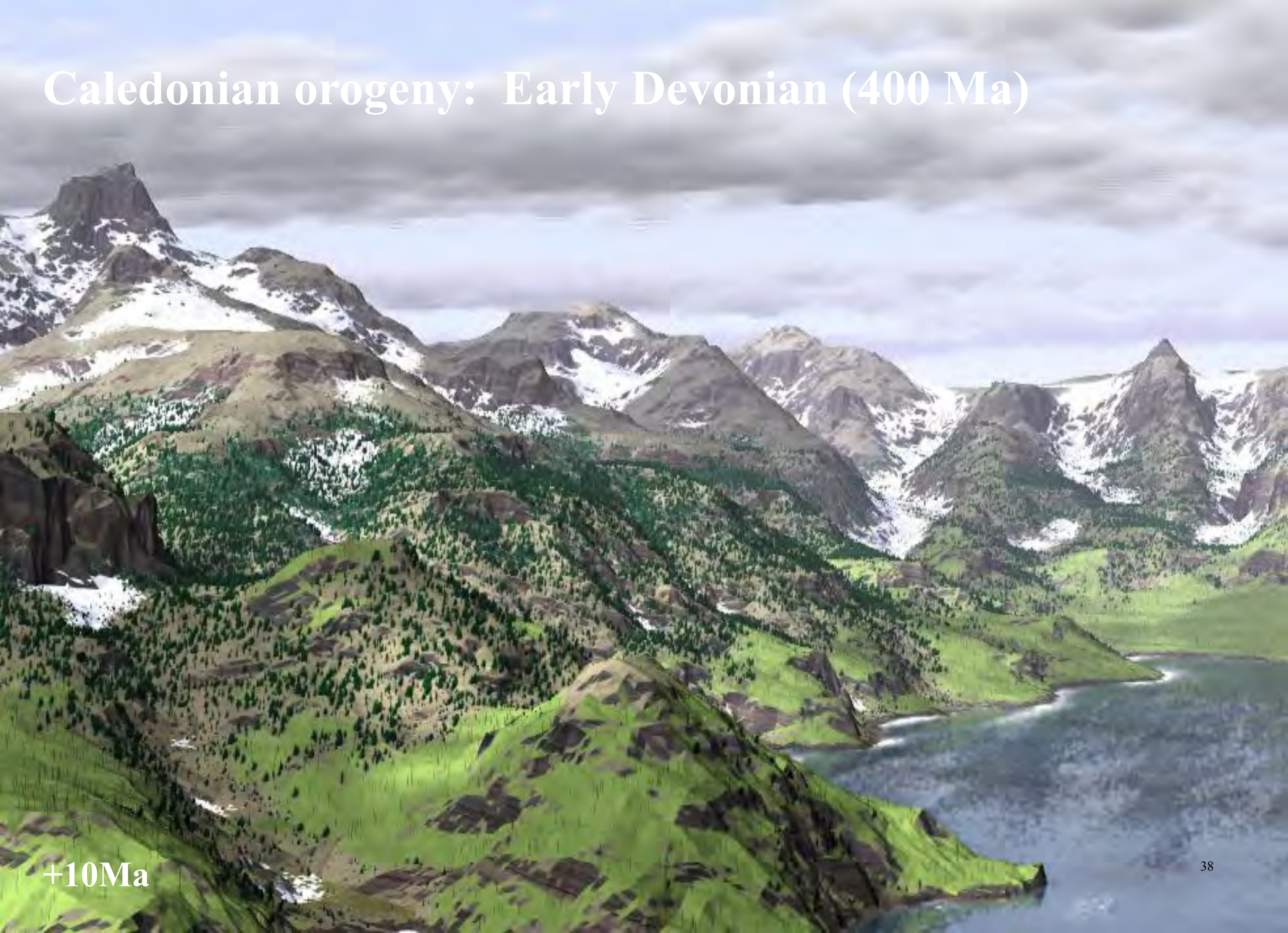


Sequence stratigraphy

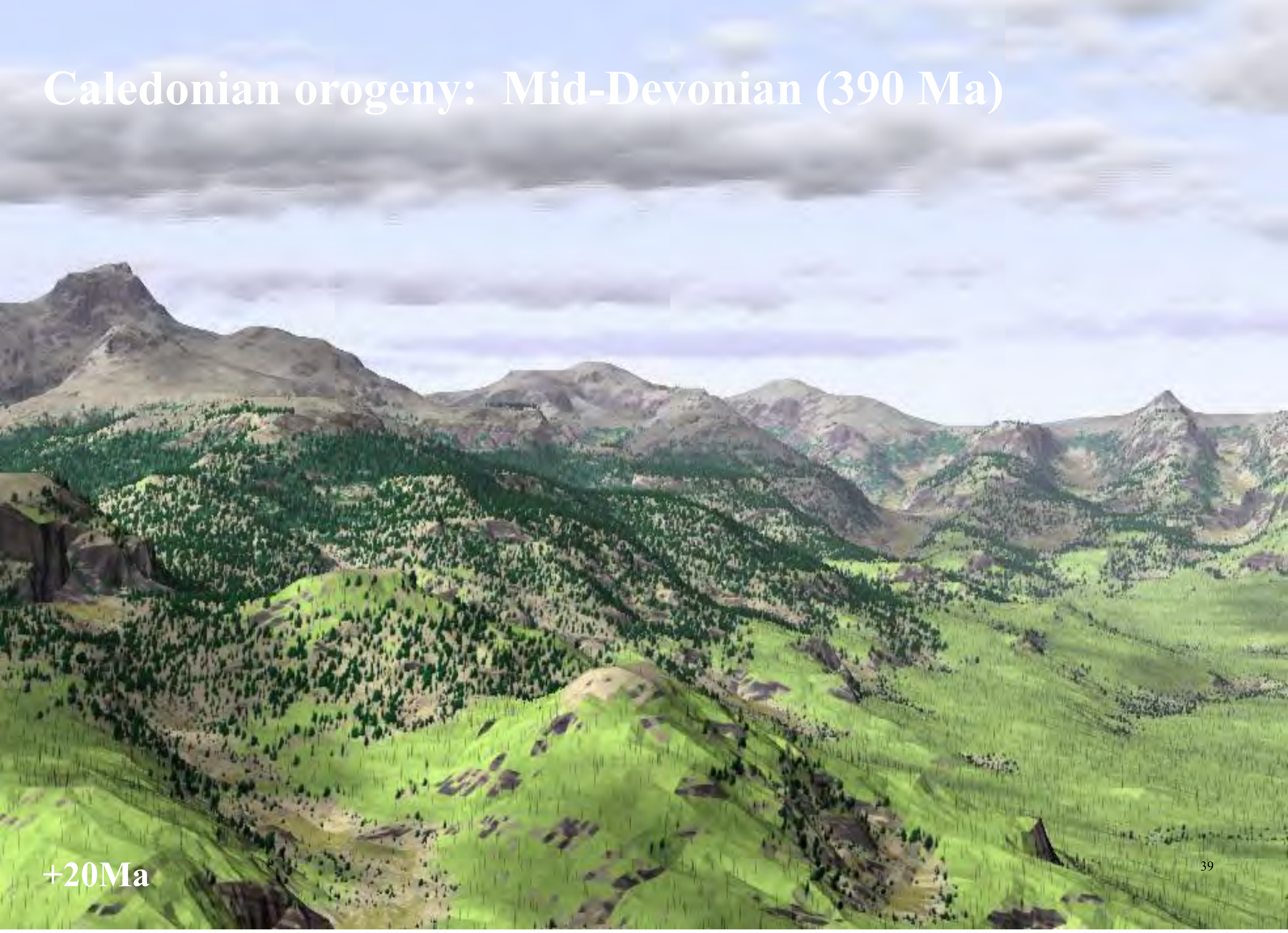
The clastic input volume (i.e. the depositional distance and thickness), sea-level change, and tectonic subsidence are all **specified as a function of time**. The colours show the average porosity. The wedge comprises 4 main stratigraphic sequences, each of which is characterised by patterns of offlap and onlap. The offlap and onlap reflect a sea-level fall and rise respectively.



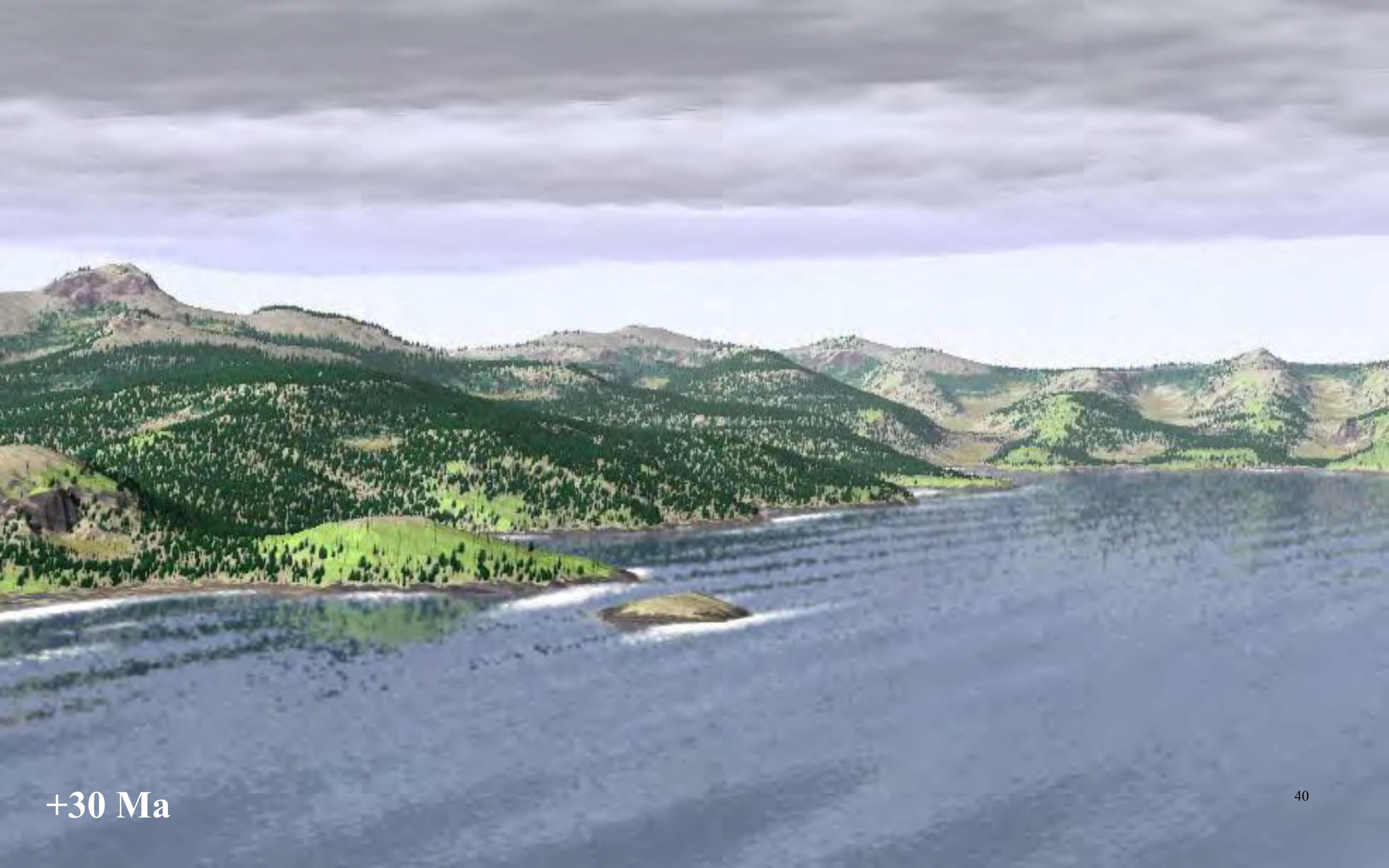
Caledonian orogeny: Early Devonian (400 Ma)



Caledonian orogeny: Mid-Devonian (390 Ma)



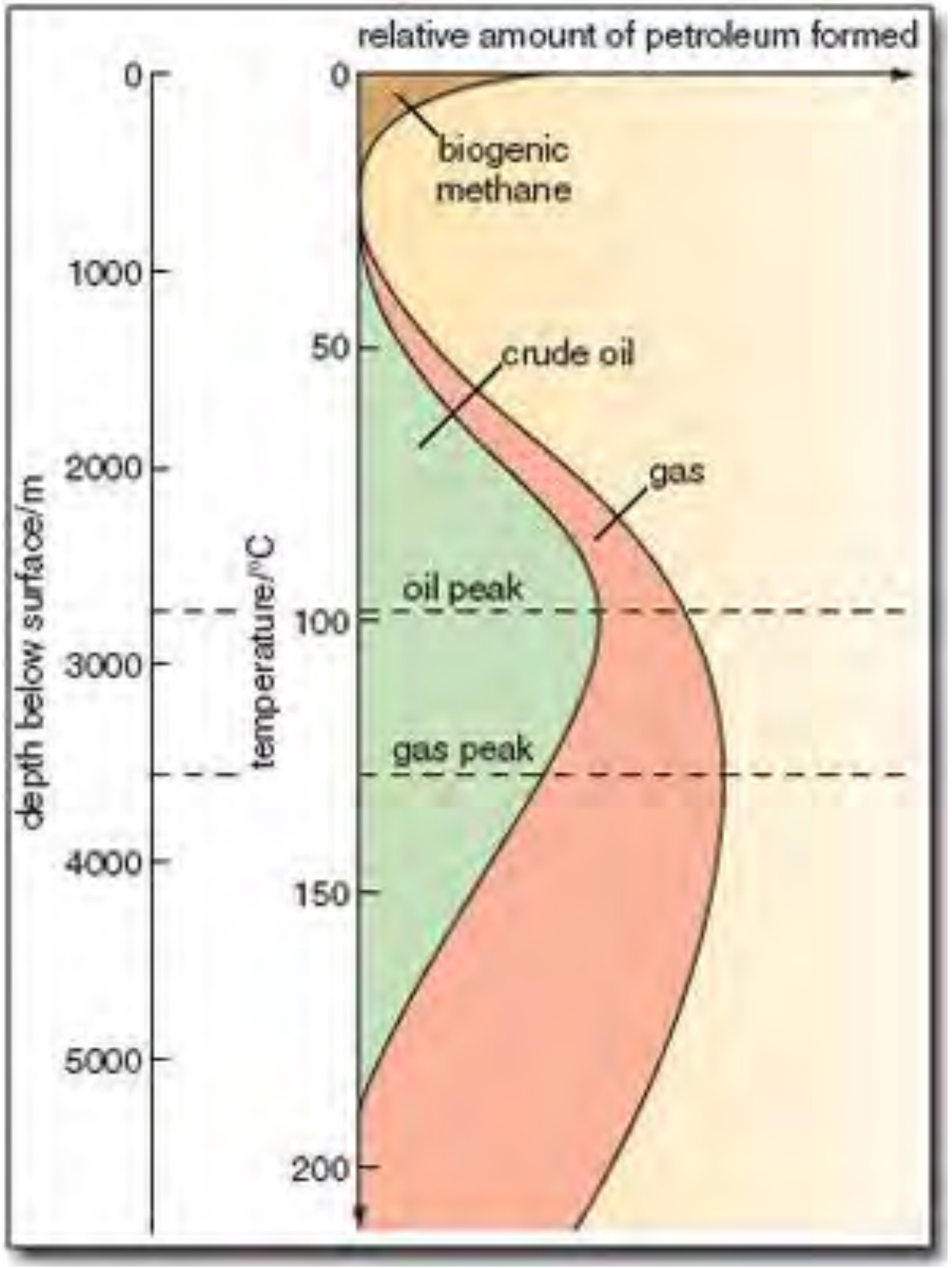
Caledonian orogeny: Mid-Devonian (380 Ma)



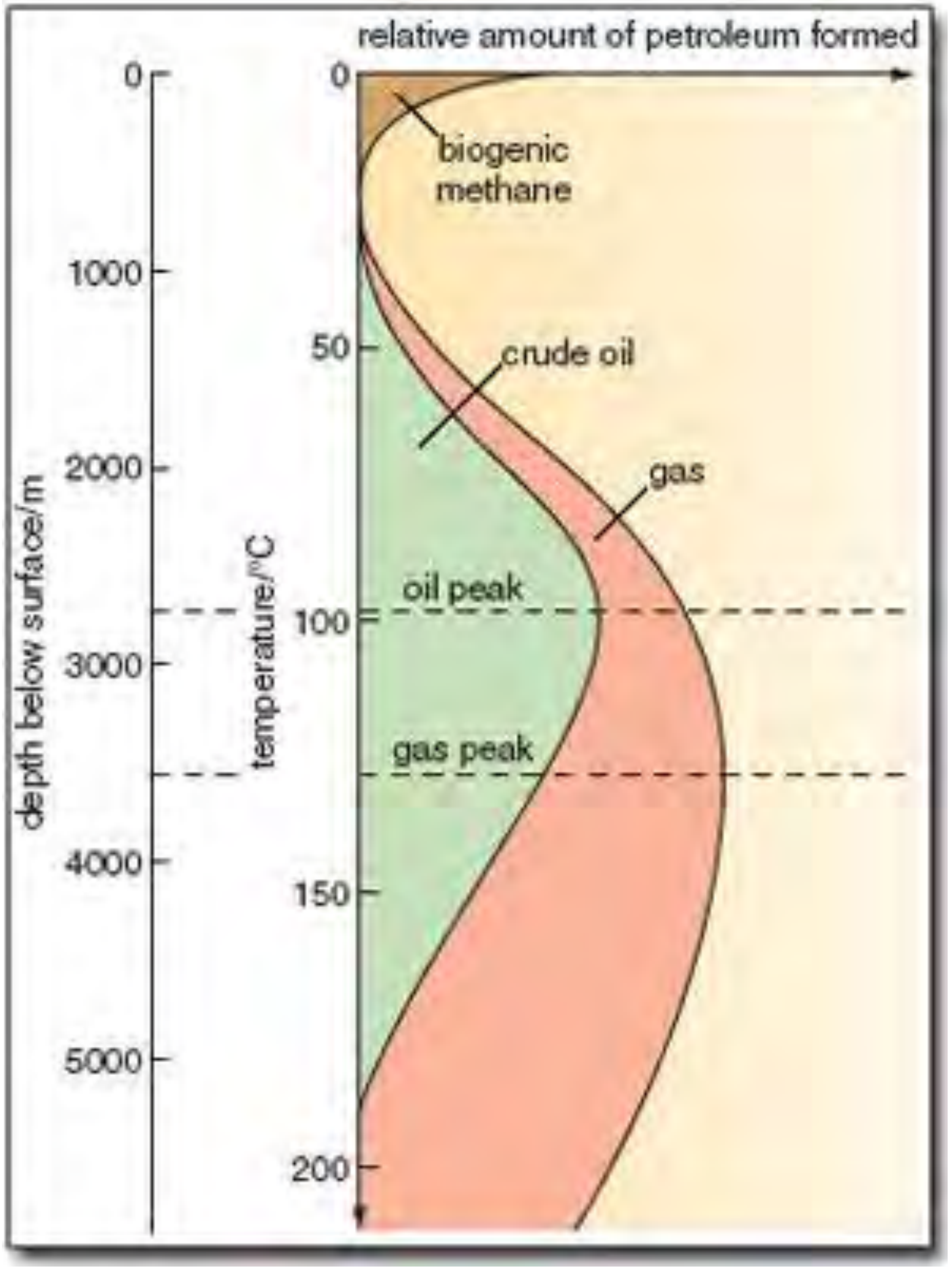
+30 Ma

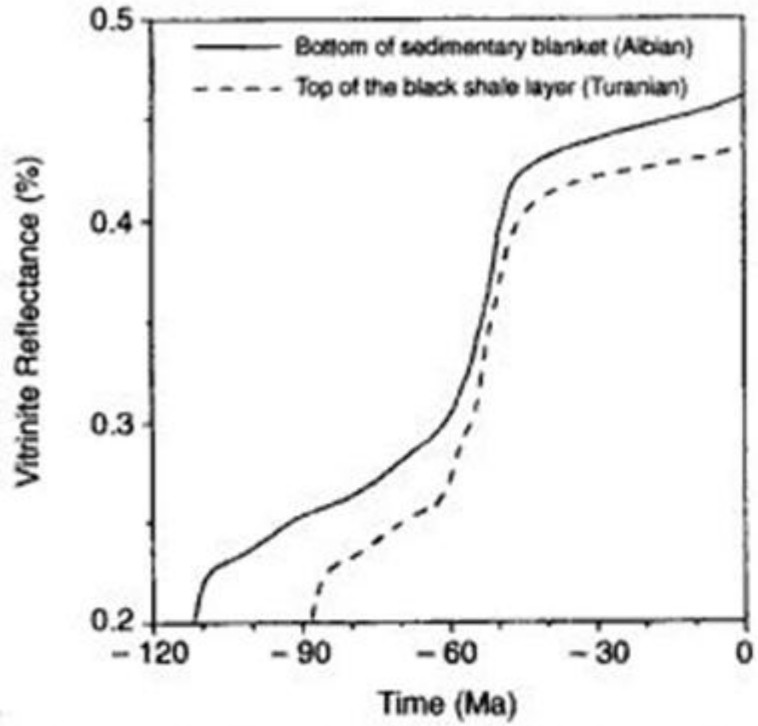
Caledonian orogeny: Late Devonian (360 Ma)

Hydrocarbon maturation



Hydrocarbon maturation





Thermal history modeling

To evaluate the temperature history of stratigraphic layers in a sedimentary basin.

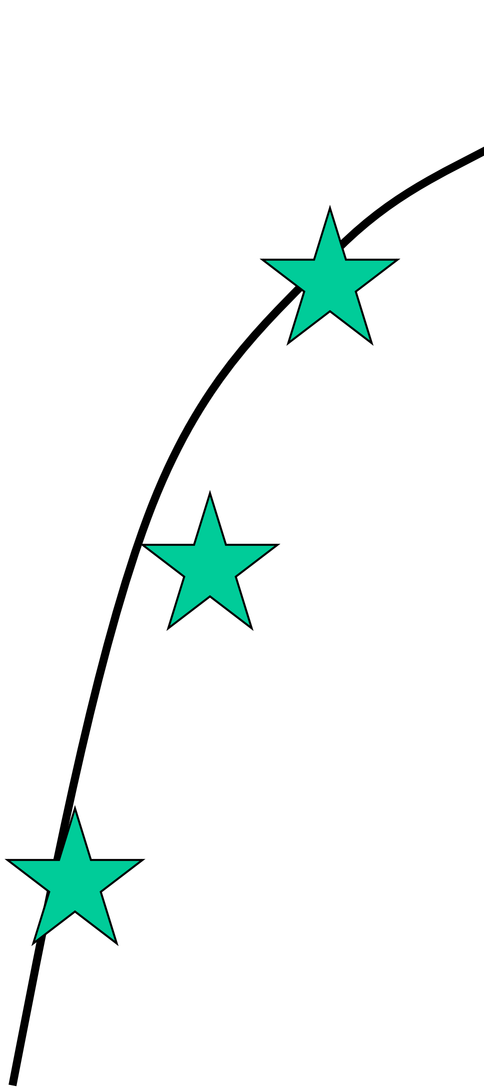
This is usually calibrated using **thermal indicator** data, including vitrinite reflectance (VR) and fission tracks in apatite and zircon.

The temperature history is crucial in order to evaluate the quantity, nature and volume of hydrocarnons produced from kerogens.

Thermal history modelling attempts to describe the temperature history and therefore requires a knowledge of the burial history of the stratigraphic layers which is obtained through the process of backstripping.

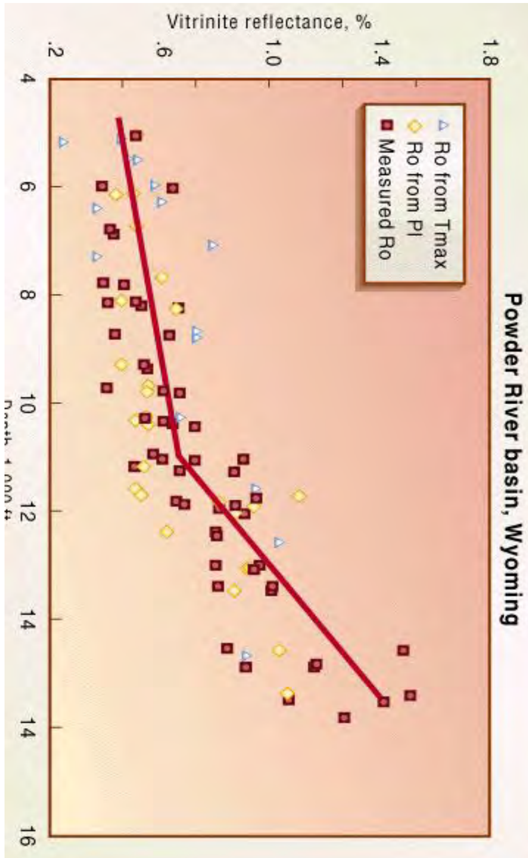
$$Q = -k\frac{dT}{dz} \qquad T_{z,t} = T_t^0 + Q_t \int_0^z \frac{dz'}{k_{z'}}$$

Temperature measurements



T max = ?

Wellbore temperatures (and derived heat flow) are calculated based on 2 or more real measurements (circulation time)



VR-data measurements

Vitrinite reflectance

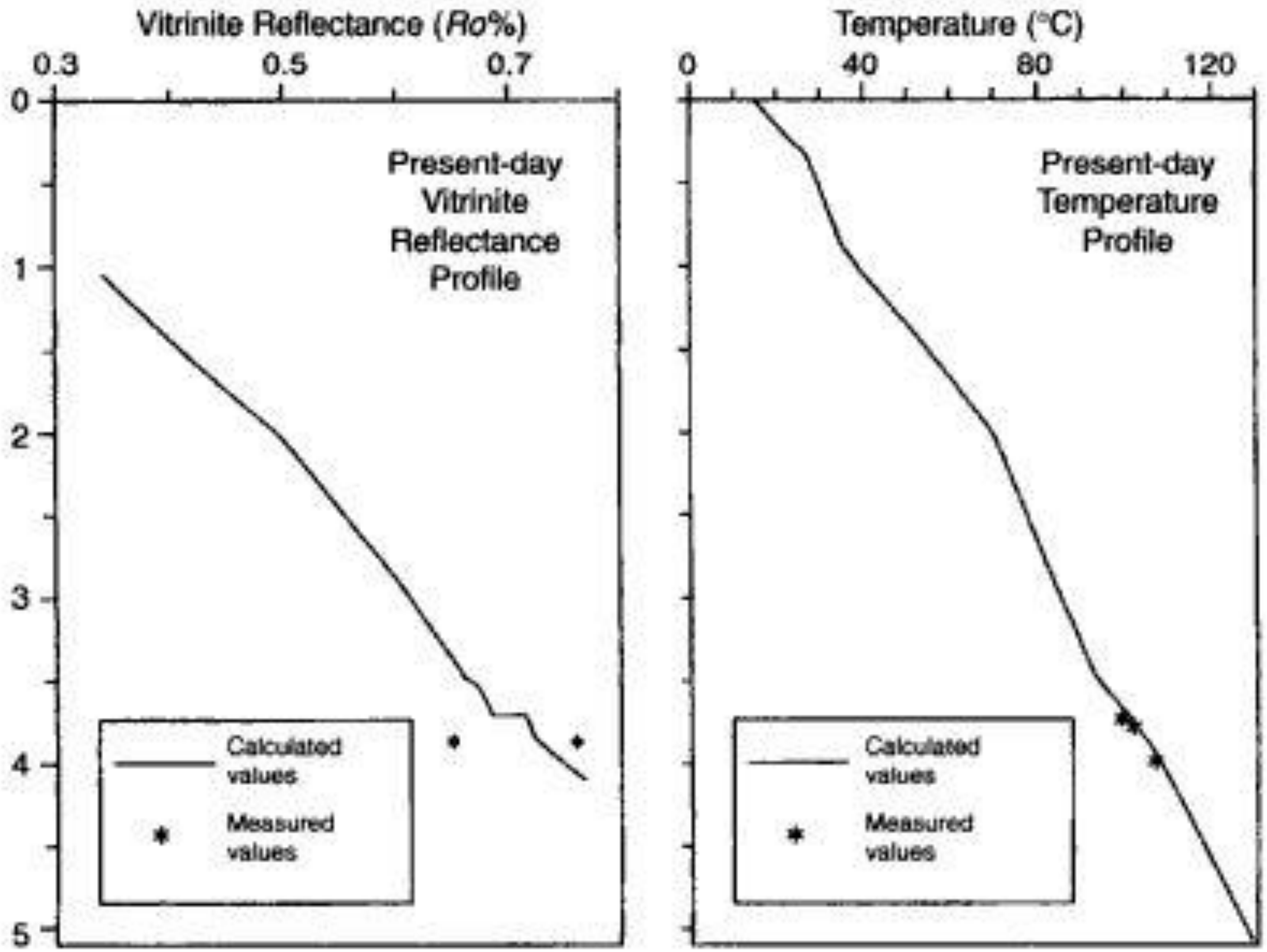


Figure 2.8 Vitrinite reflectance and temperature in the present sedimentary column of the Takhoukht region, Sahara.

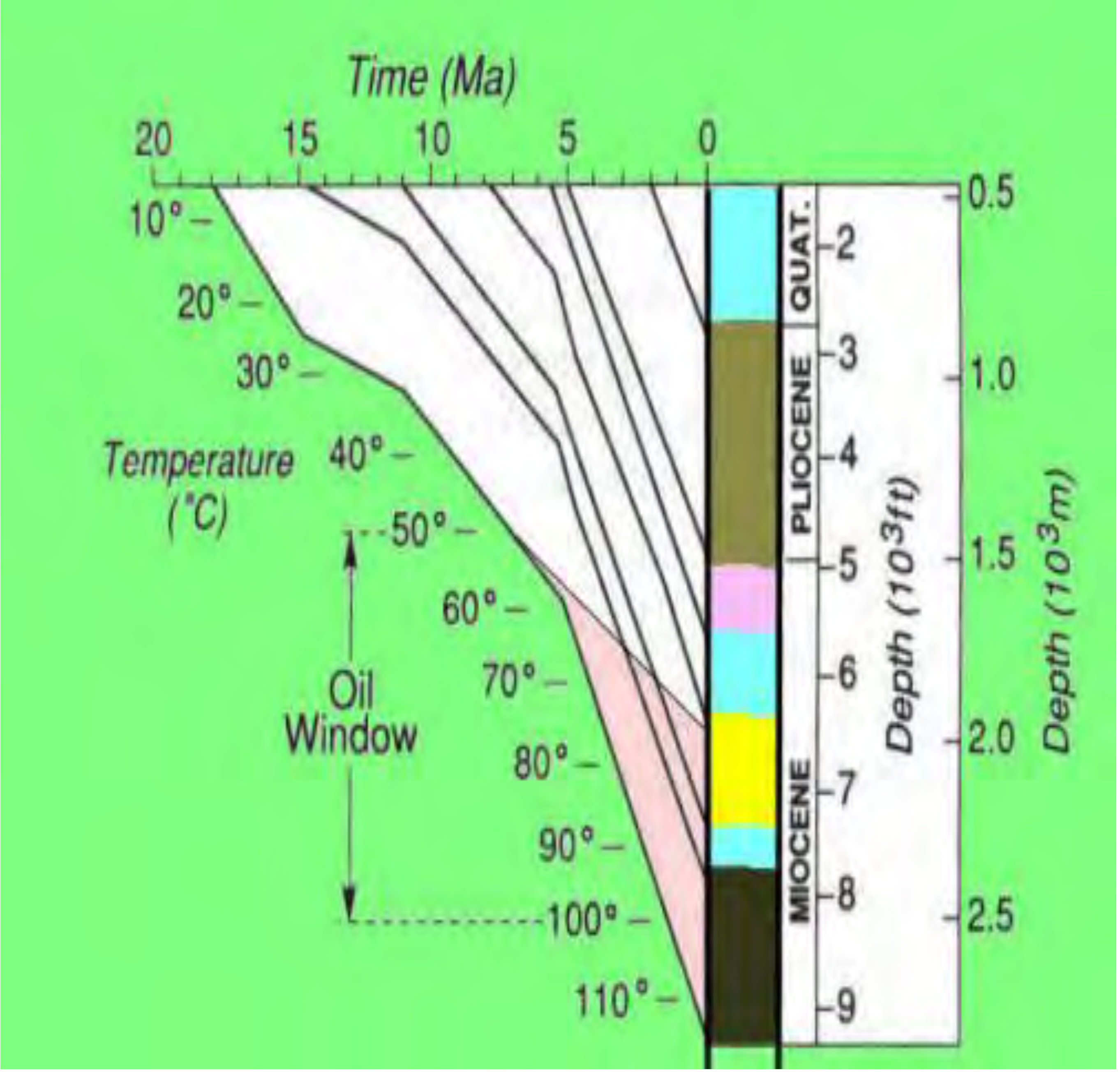
Vitrinite reflectance

Table 3.1 Relationship of the maturation stages of organic matter with the values of *Ro*% and *TTI*
[after Waples, 1984]

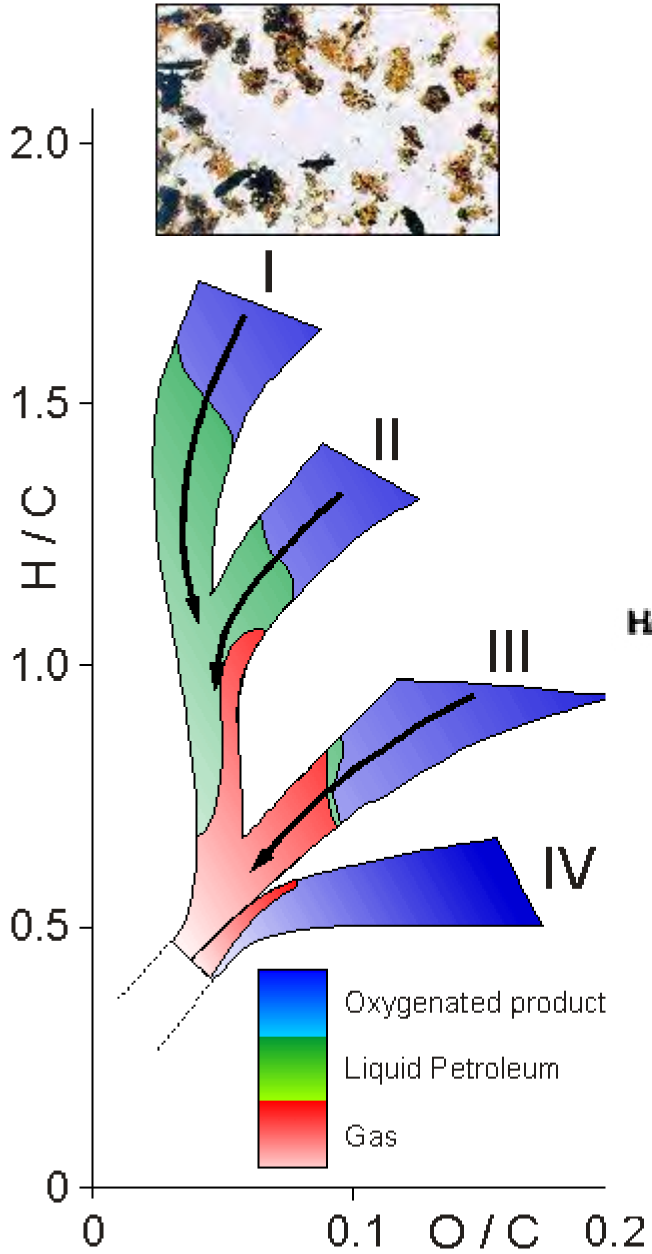
Maturation stages	Start of liquid HC generation	50% Maturation of kerogen	Maximum of liquid HC generation	End of liquid HC generation	Condensate generation	Start of dry gas generation
Ro%	0.50–0.65	0.80	0.90–1.00	1.30	1.75	2.00–2.30
TTI	3–15	35	50–75	160	500	900–1600

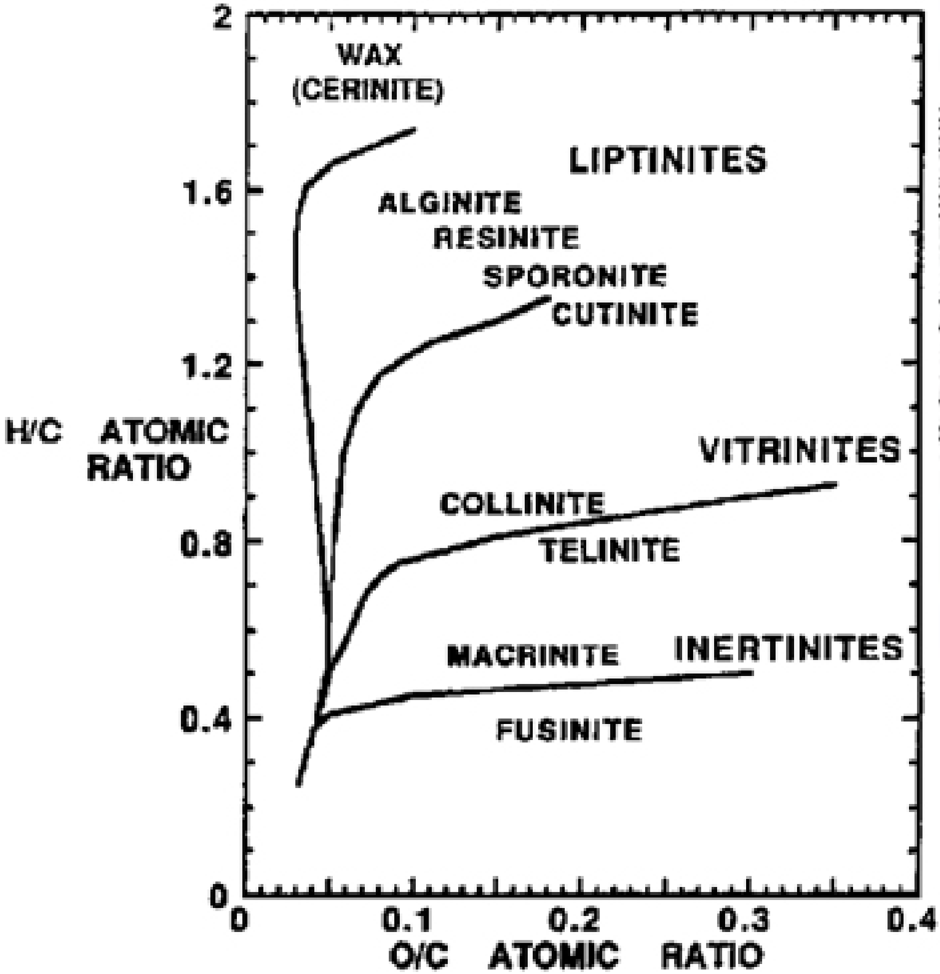
Remarks: *TTI* – Time- Temperature Index (see text).

Hydrocarbon maturation

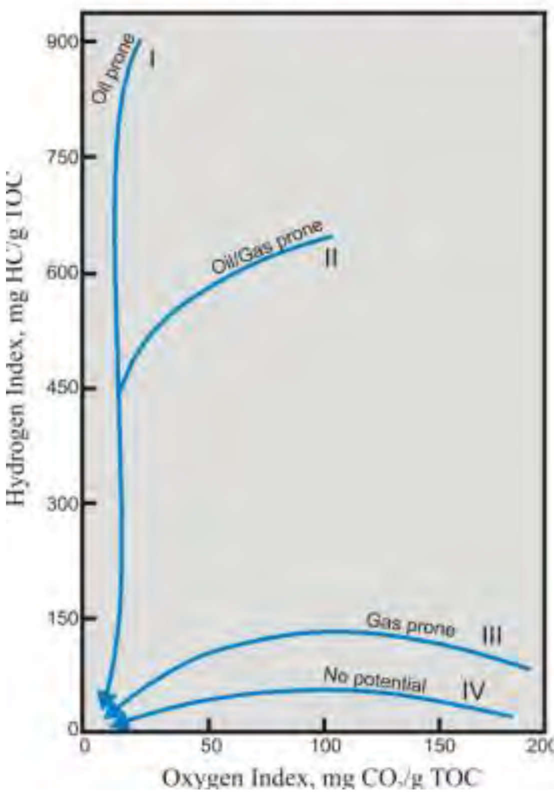


Kerogen types





Modified van Krevelen diagram



Hydrocarbon types