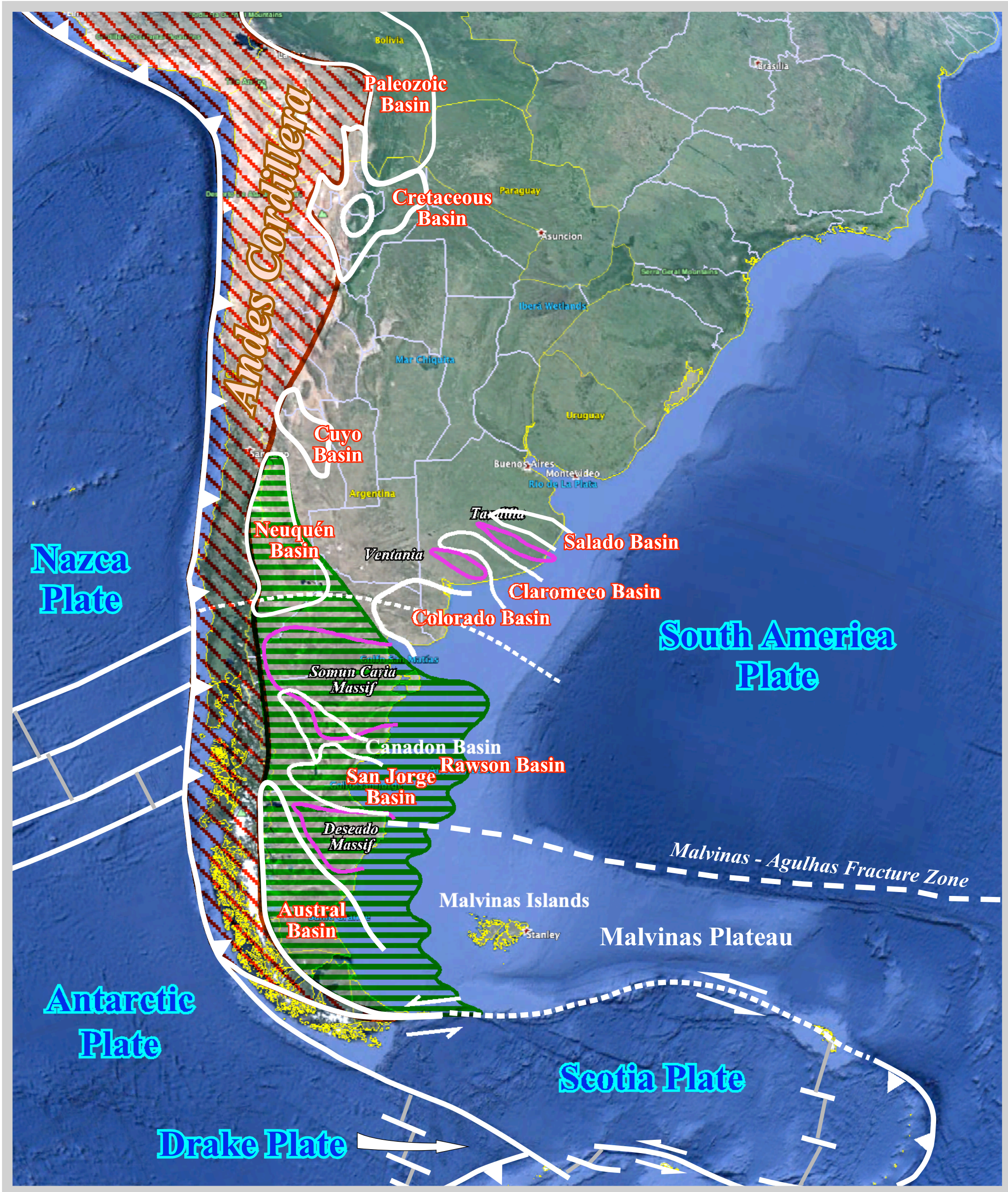
Argentina Sedimentary Basins

(Introduction)

CCramez

Main Argentina Geographic Basins



Paleozoic Basin

Cretaceous Basin

Cuyo Basin

Neuquén Basin

Salado Basin

Claromeco Basin

Colorado Basin

Canadon Basin

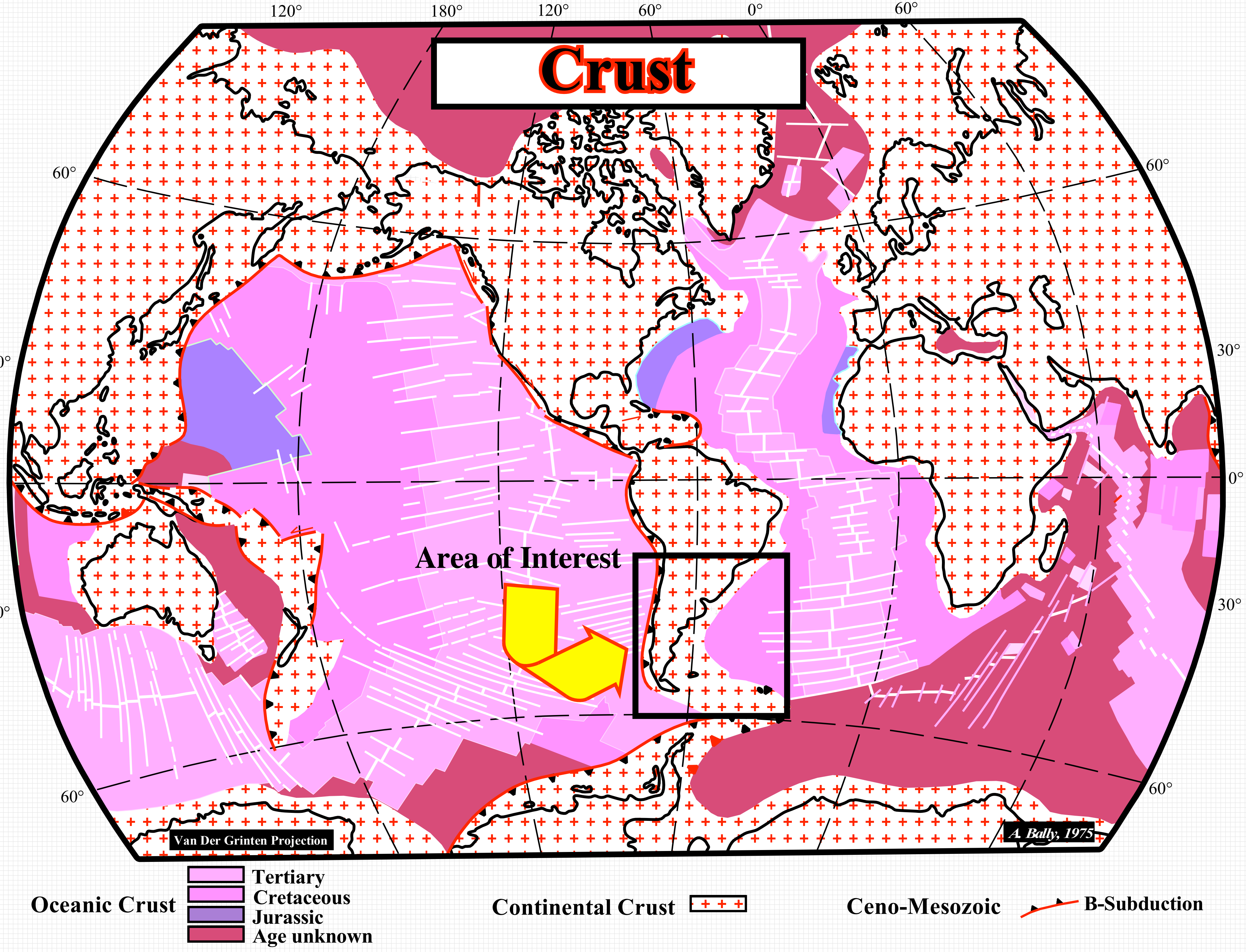
Rawson basin

San Jorge Basin

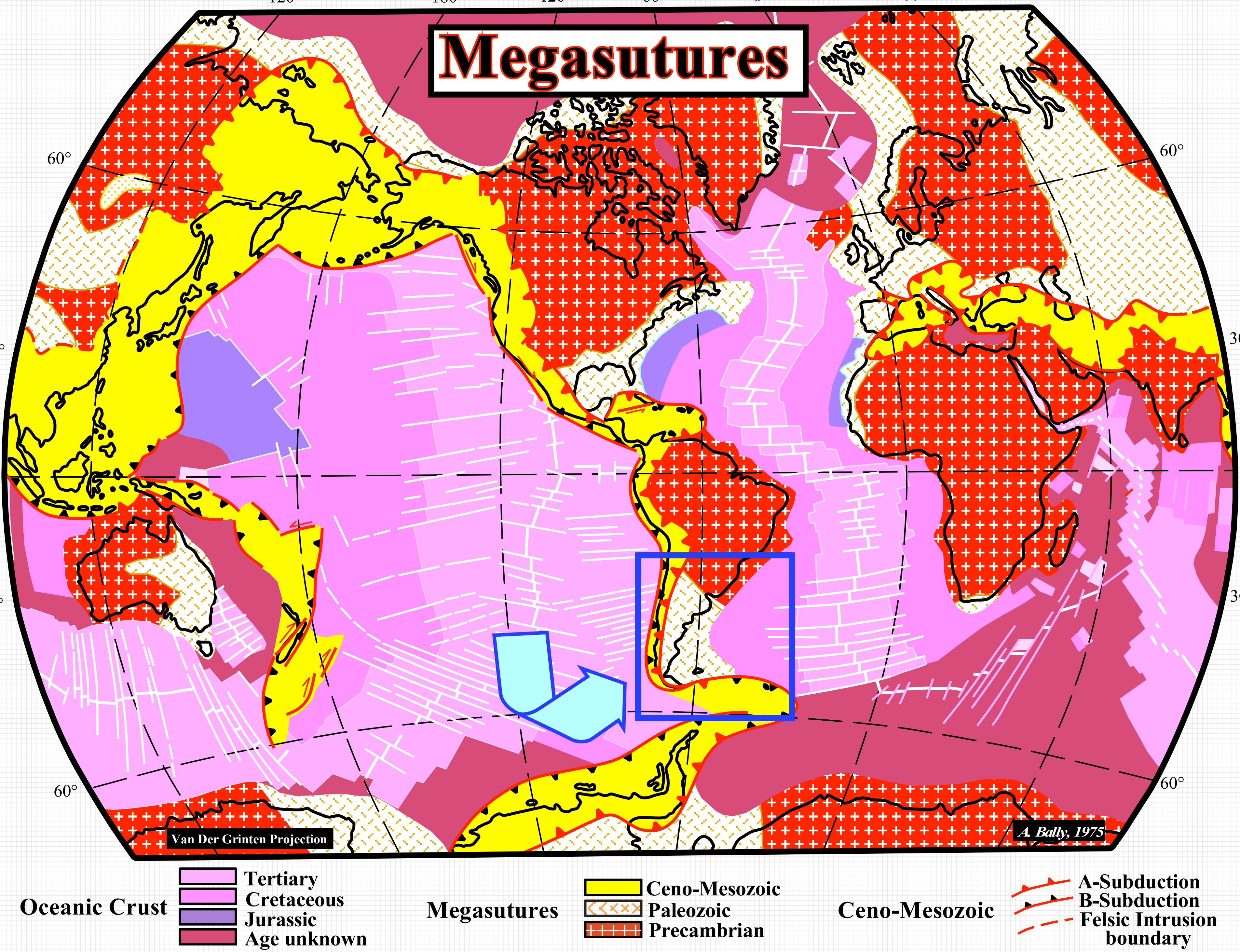
Austral Basin

Malvinas Basin

Andes Cordillera



Crust
120°
180°
120°
60°
0°
60°
60°
60°
30°
30°
0°
0°
30°
30°
60°
60°
Area of Interest
Van Der Grinten Projection
A. Bally, 1975
Oceanic Crust
Tertiary
Cretaceous
Jurassic
Age unknown
Continental Crust
Ceno-Mesozoic
B-Subduction


120°
180°
120°
60°
0°
60°
60°
60°
30°
30°
0°
0°
30°
30°
60°
60°
Megasutures
Van Der Grinten Projection
A. Bally, 1975
Oceanic Crust
Tertiary
Cretaceous
Jurassic
Age unknown
Megasutures
Ceno-Mesozoic
Paleozoic
Precambrian
Ceno-Mesozoic
A-Subduction
B-Subduction
Felsic Intrusion
boundary

Bally's Classification

CLASS A

Basins not associated with formation of Megasutures

Class A1 Basins related to formation of oceanic crust

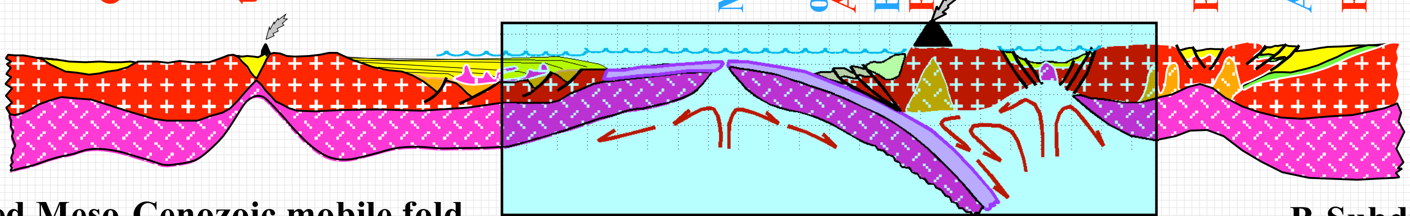
Class A2 Basins located on pre-Mesozoic continental lithosphere

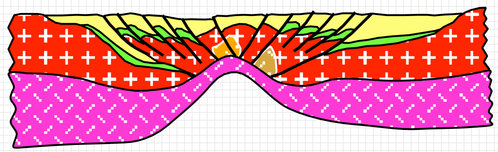
CLASS B

Basins associated with formation of Megasutures

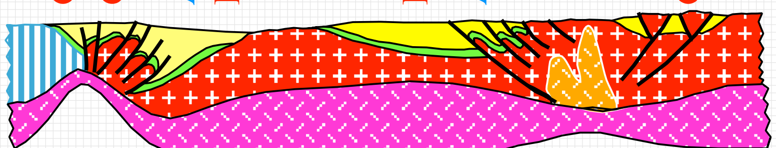
Class B1
Episutural Basins

Class B2
Perisutural Basins





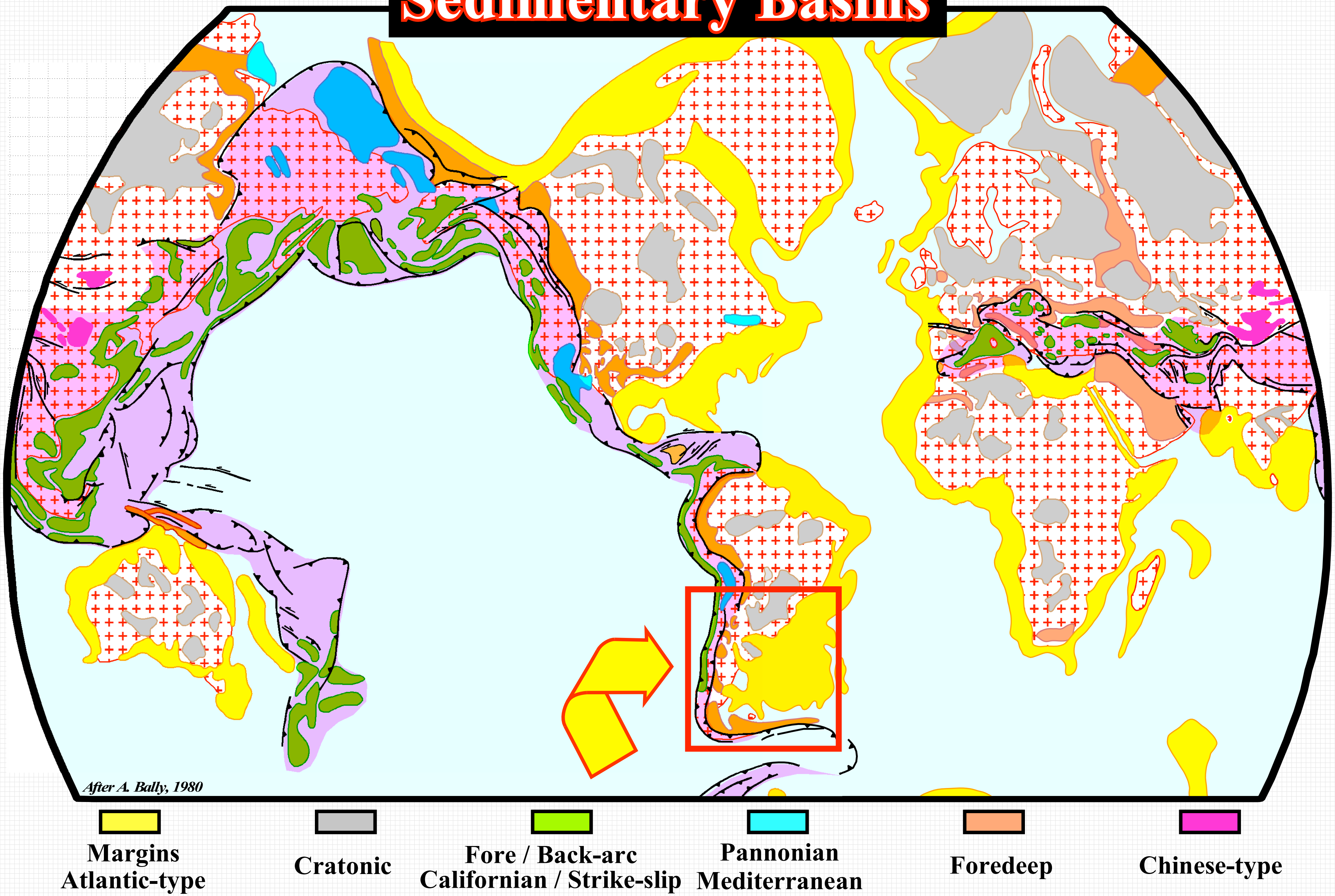
The combined Meso-Cenozoic mobile fold belts, or Megasutures, record the complex accretion and deformation in a dominantly compressional regime.
The pristine Meso-Cenozoic oceanic crust and the associated passive margins can be viewed as the extensional counterpart of the contemporaneous compressional global fold belt with their associated margins.



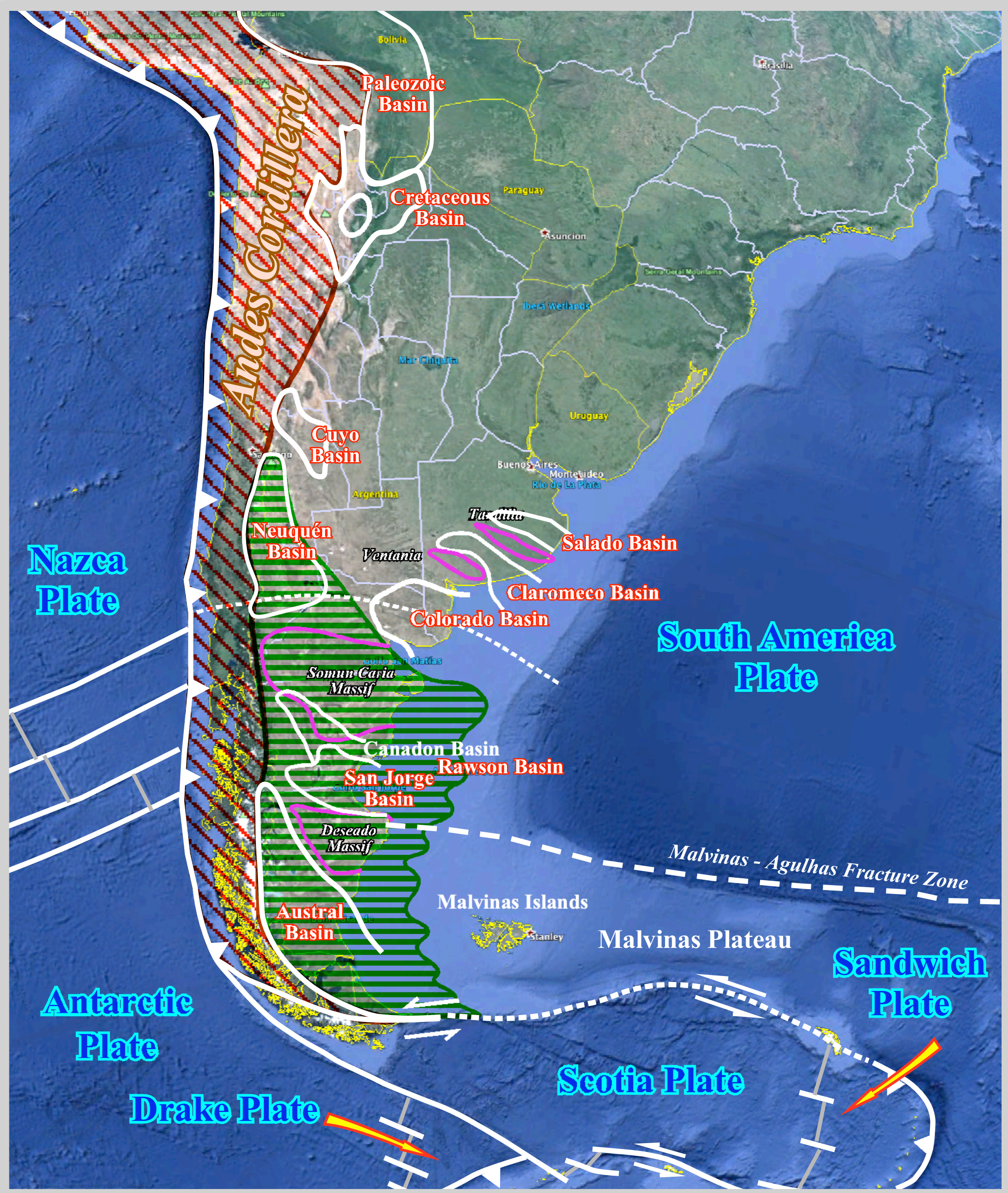
B-Subduction (Benioff) where an oceanic lithosphere slab dips under the sialic continent or an island arc dips into the mantle.
A-Subduction (Ampferer) where some amounts of sialic crust may be disposed at in-termediate depths below the megasuture.
This is accompanied by large scale décollement folding and widespread overthrusting of the overlying sedimentary cover.

After A. Bally, 1980

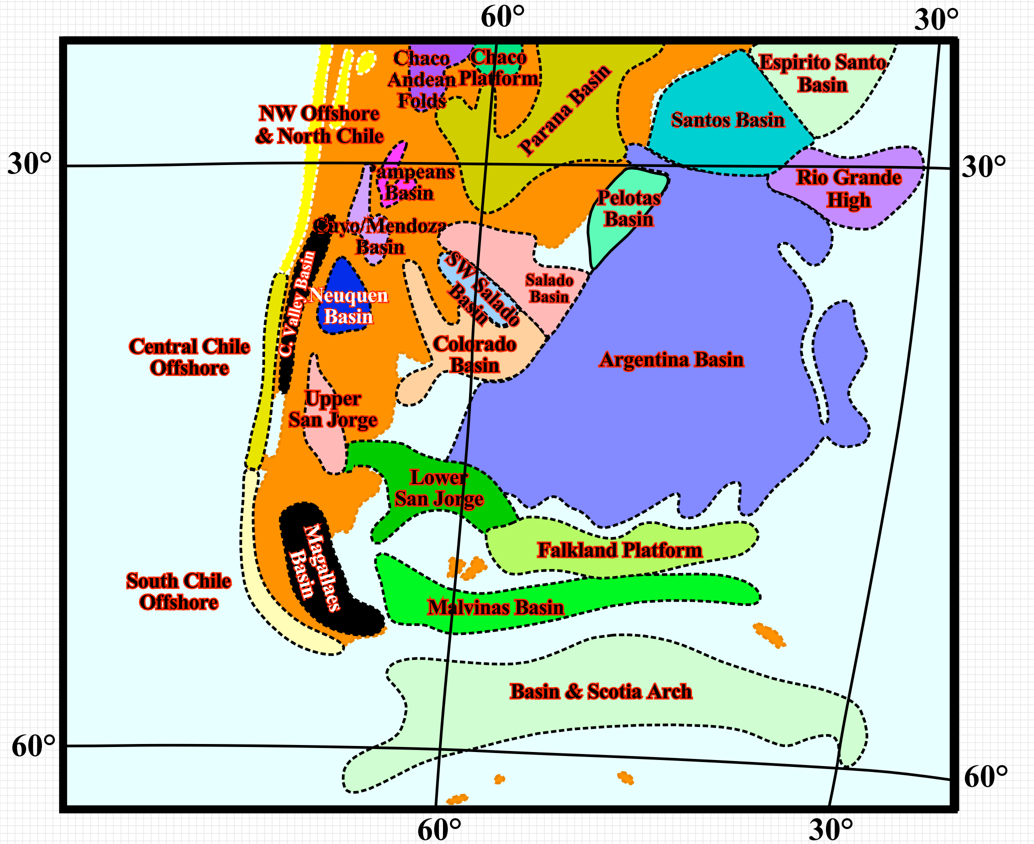
Sedimentary Basins



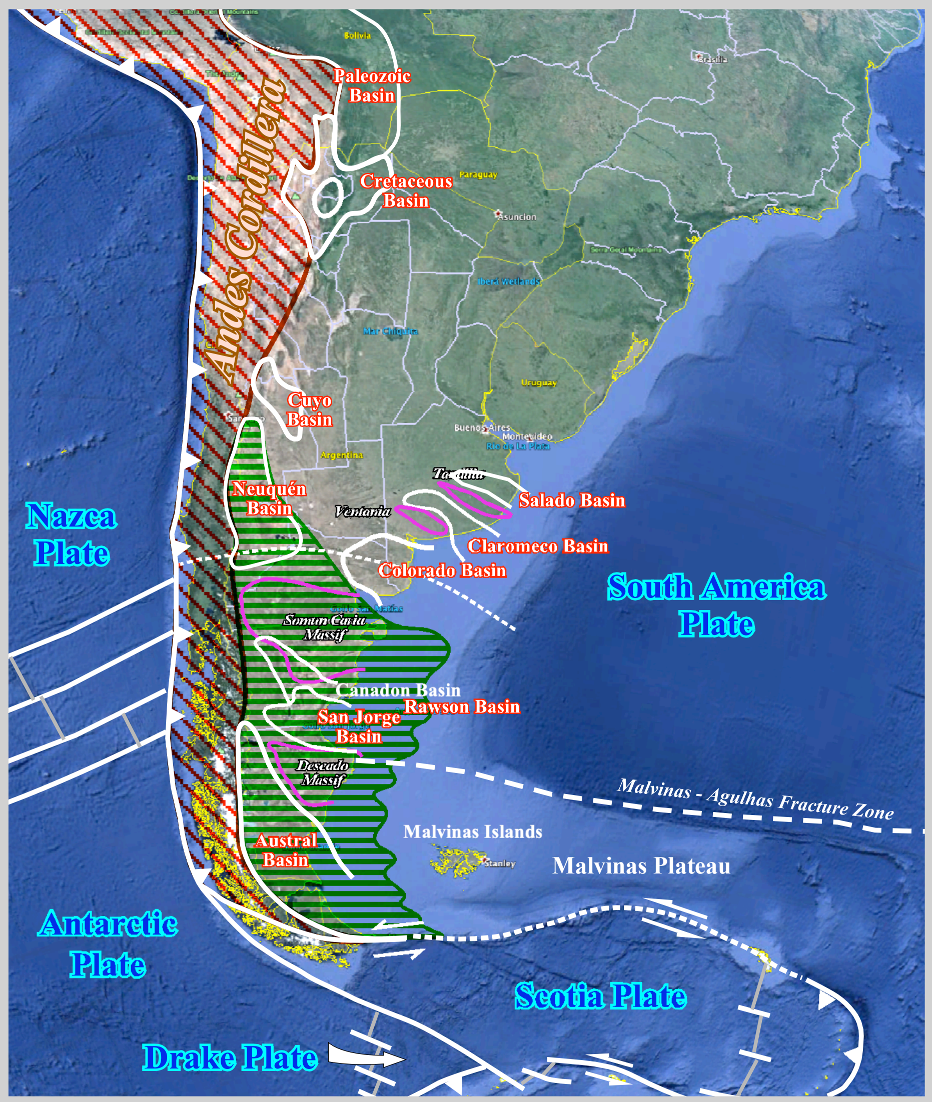
Main Argentina Geographic Basins



International Basins Terminology



Main Argentina Geographic Basins



Paleozoic Basin (Foredeep, Fold Belt)

Cretaceous Basin (Rift-Type Basin, Foreland)

Cuyo Basin (Back-arc basin below Foredeep)

Neuquén Basin (Back-arc basin below Foredeep)

Salado Basin (Rift-Type, Margin)

Claromeco Basin (Paleozoic Foredeep)

Colorado Basin (Rift-Type, Margin)

Canadon Basin (Rift-Type, Margin)

Rawson basin (Rift-Type, Margin)

San Jorge Basin (Rift-Type Basin, Margin)

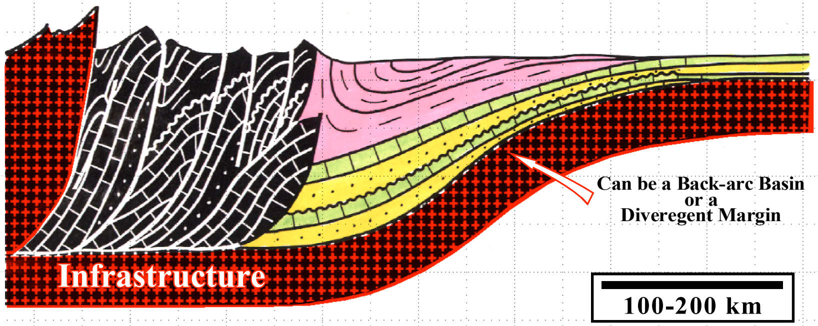
Austral Basin (Divergent Margin)

Malvinas Basin (Rift-type Basin)

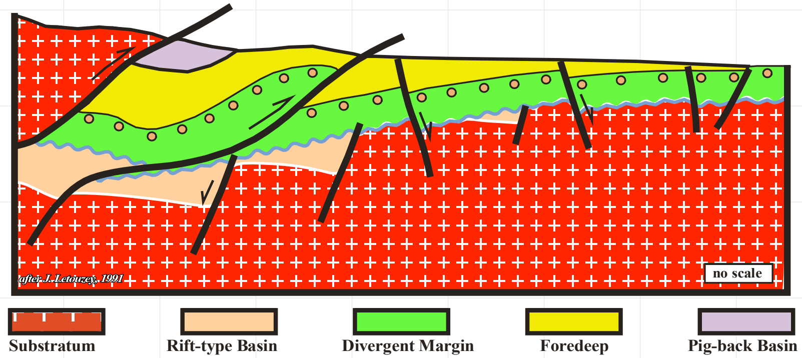
Andes Cordillera (Fold Belt)

Foredeep Basin & Infrastructure

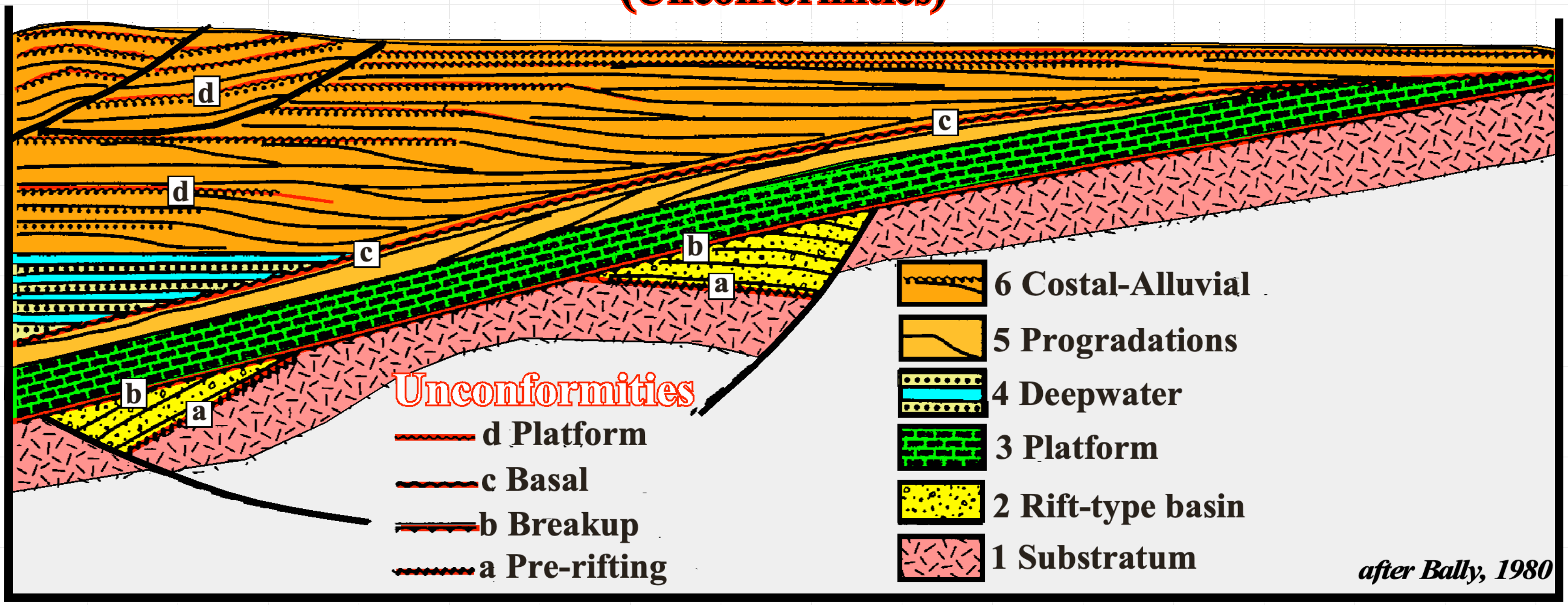
Foredeep Basin



Tectonic-Sedimentary Units

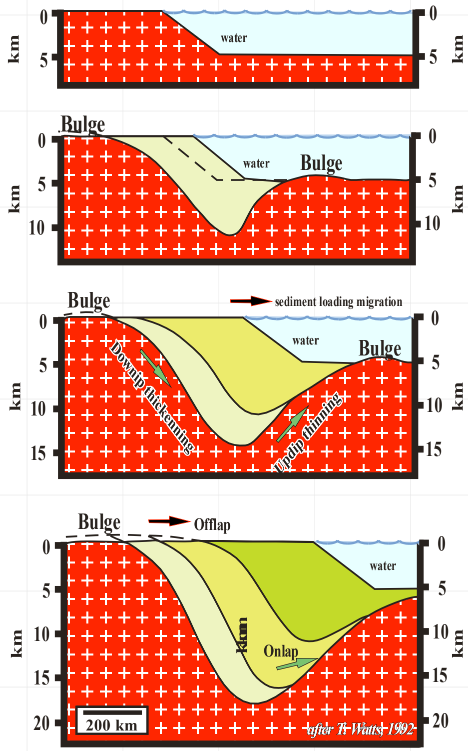


Foredeep Basin Model
(Unconformities)

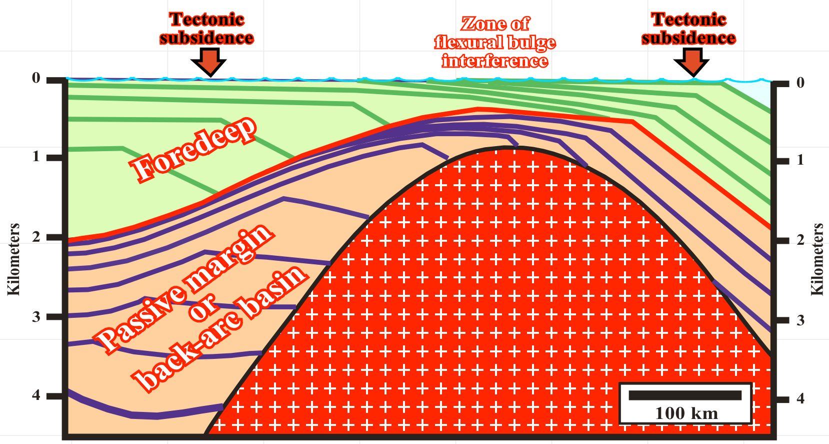


Foredeep Basin

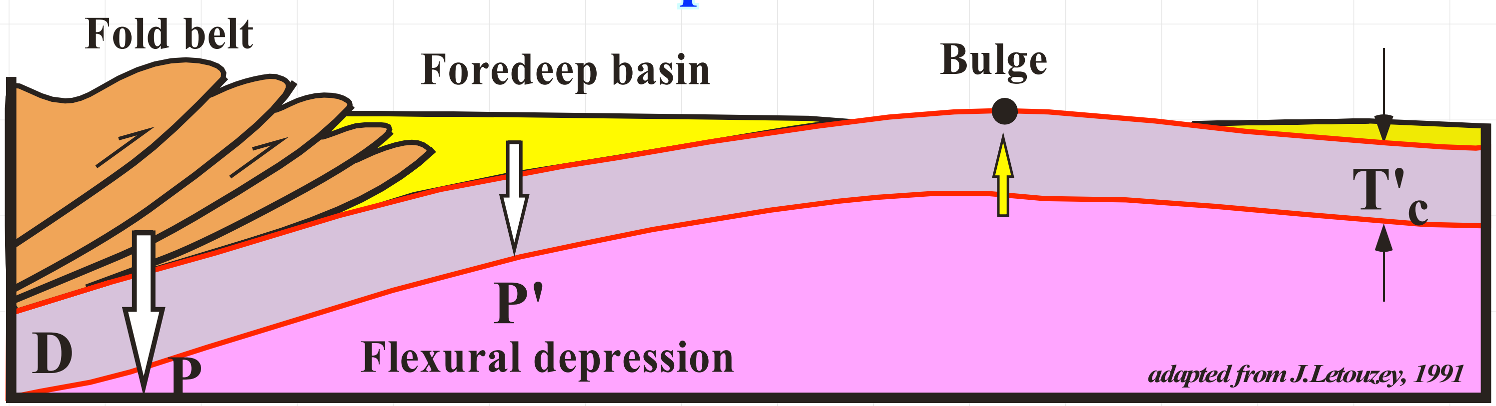
Sedimentary Loading



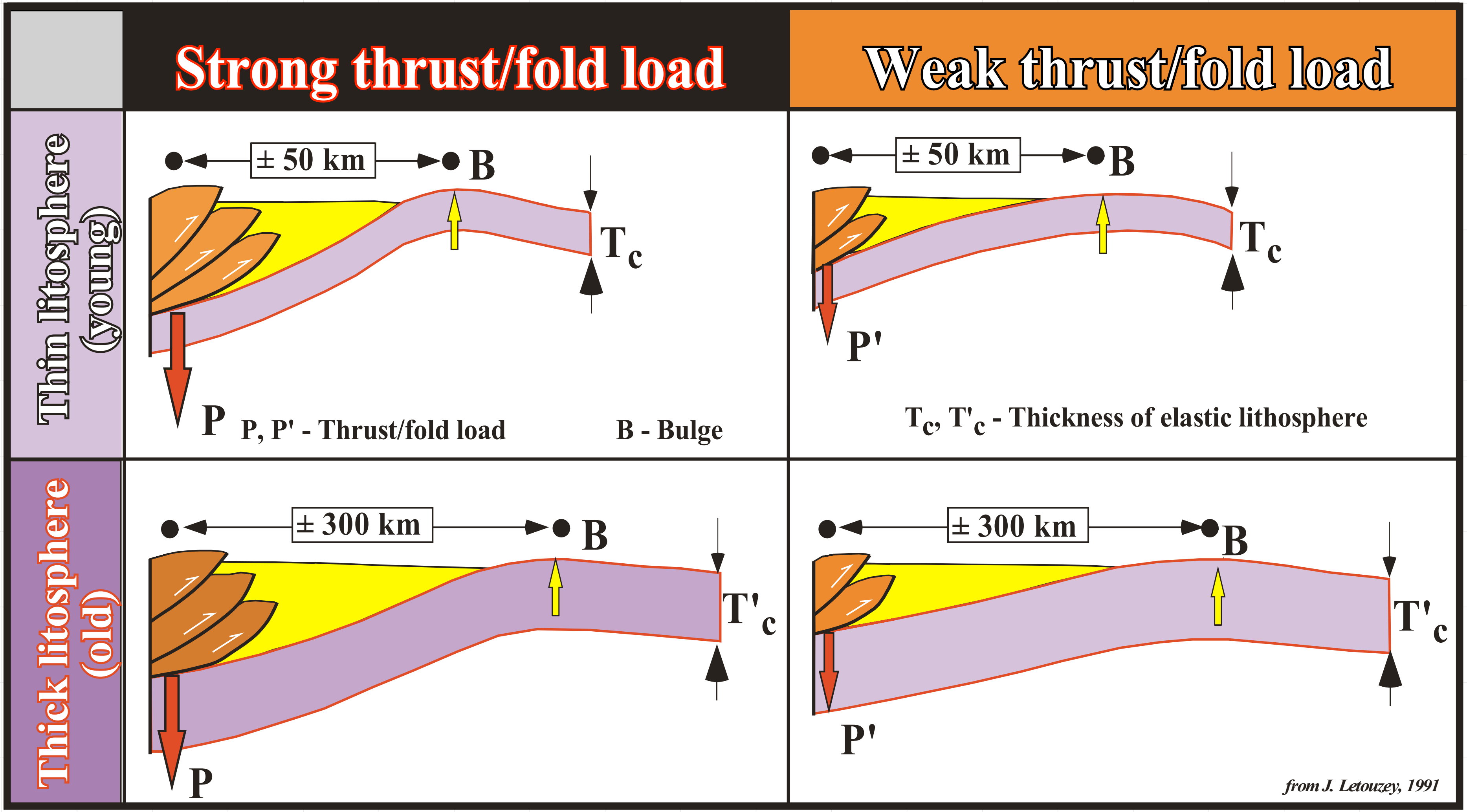
Sedimentary Loading



Foredeep Subsidence



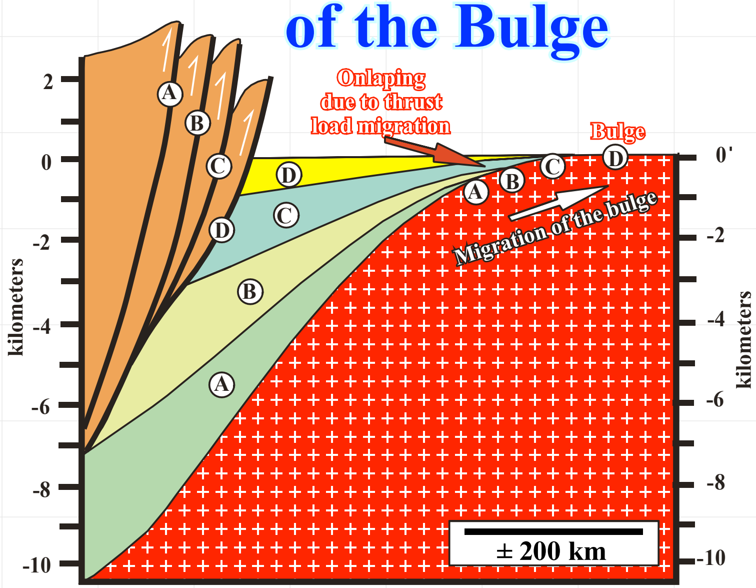
Dimensions of a Foredeep Basin



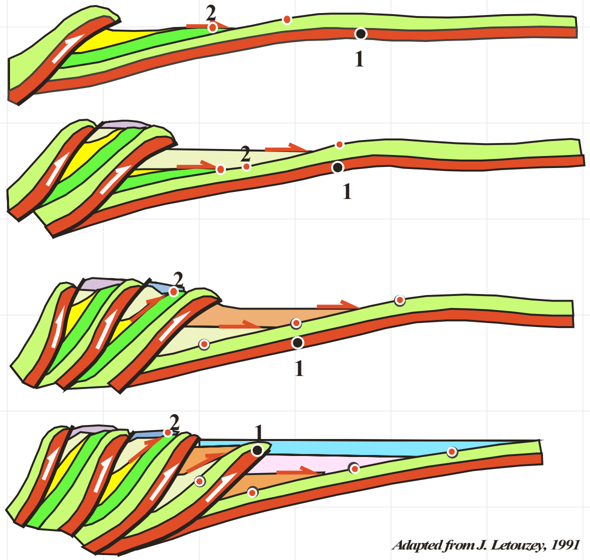
from J. Letouzey, 1991

Foredeep Basin

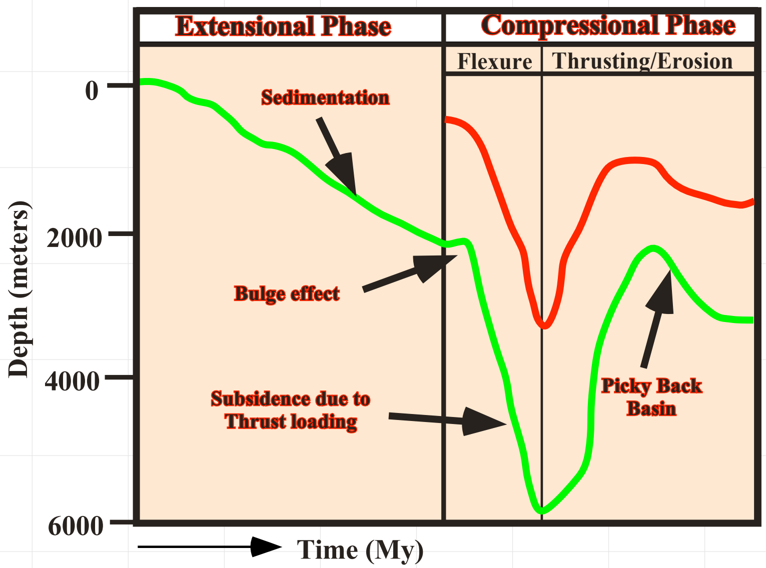
Outward Migration of the Bulge



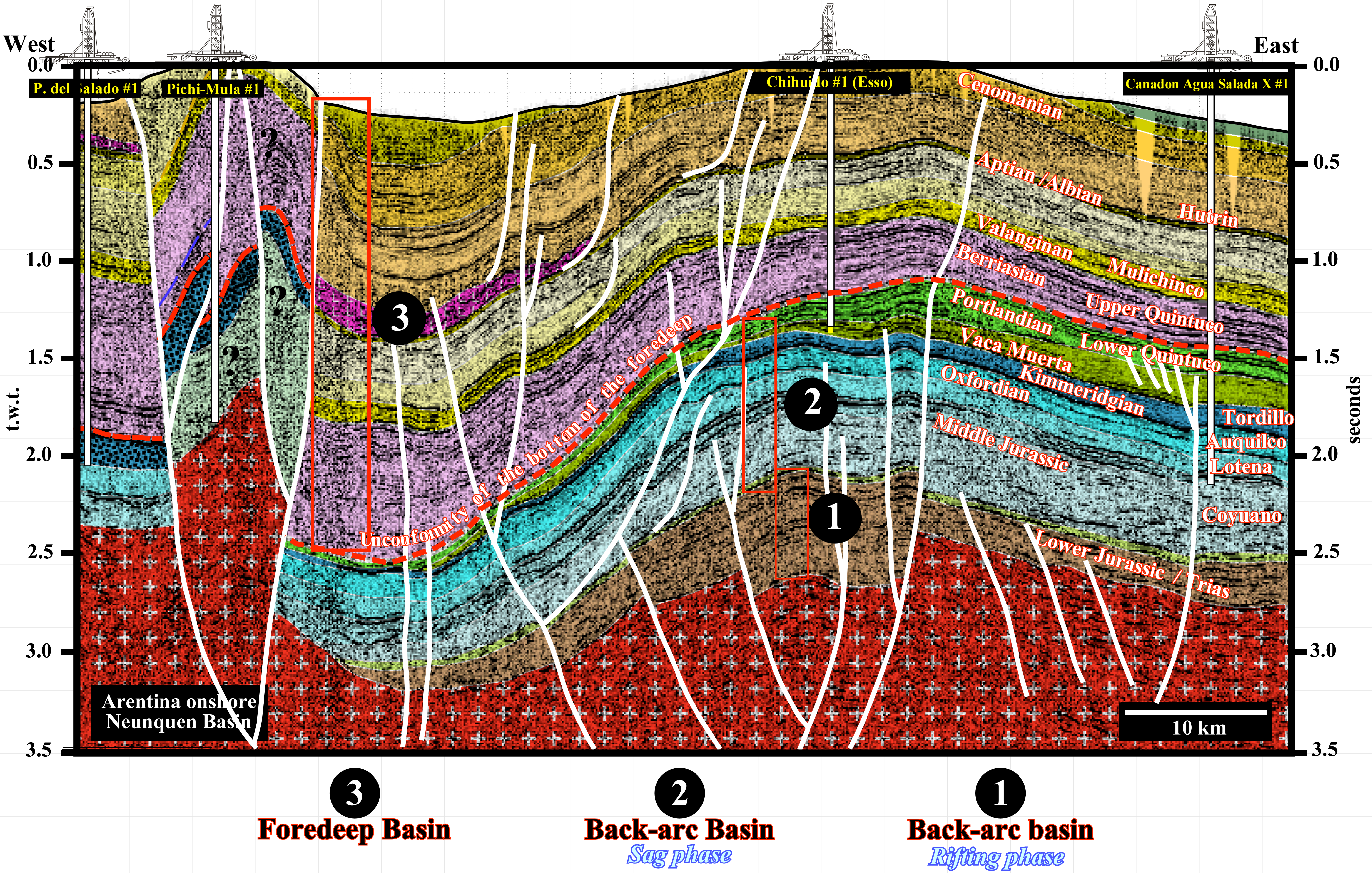
Evolution of a Foredeep



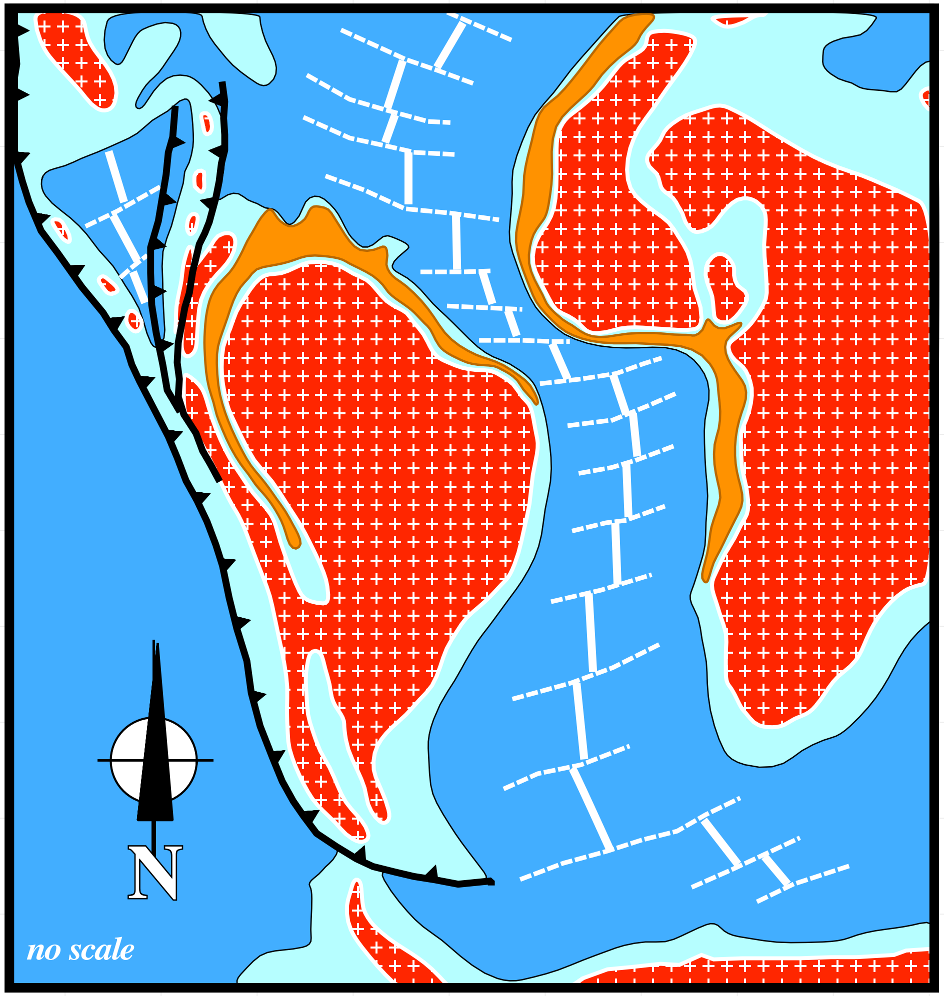
Sedimentary Burial



Argentina Foredeep Basin



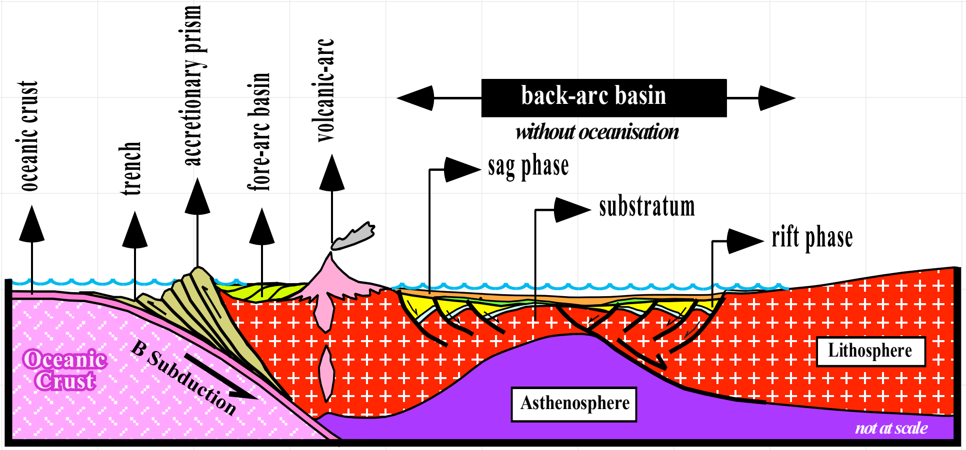
Back-arc Basins



Continent
Shallow water
Deep water
B Subduction
Transformant Fault
Potential Source Rocks
Organic Matter type II
Albian / Santonian

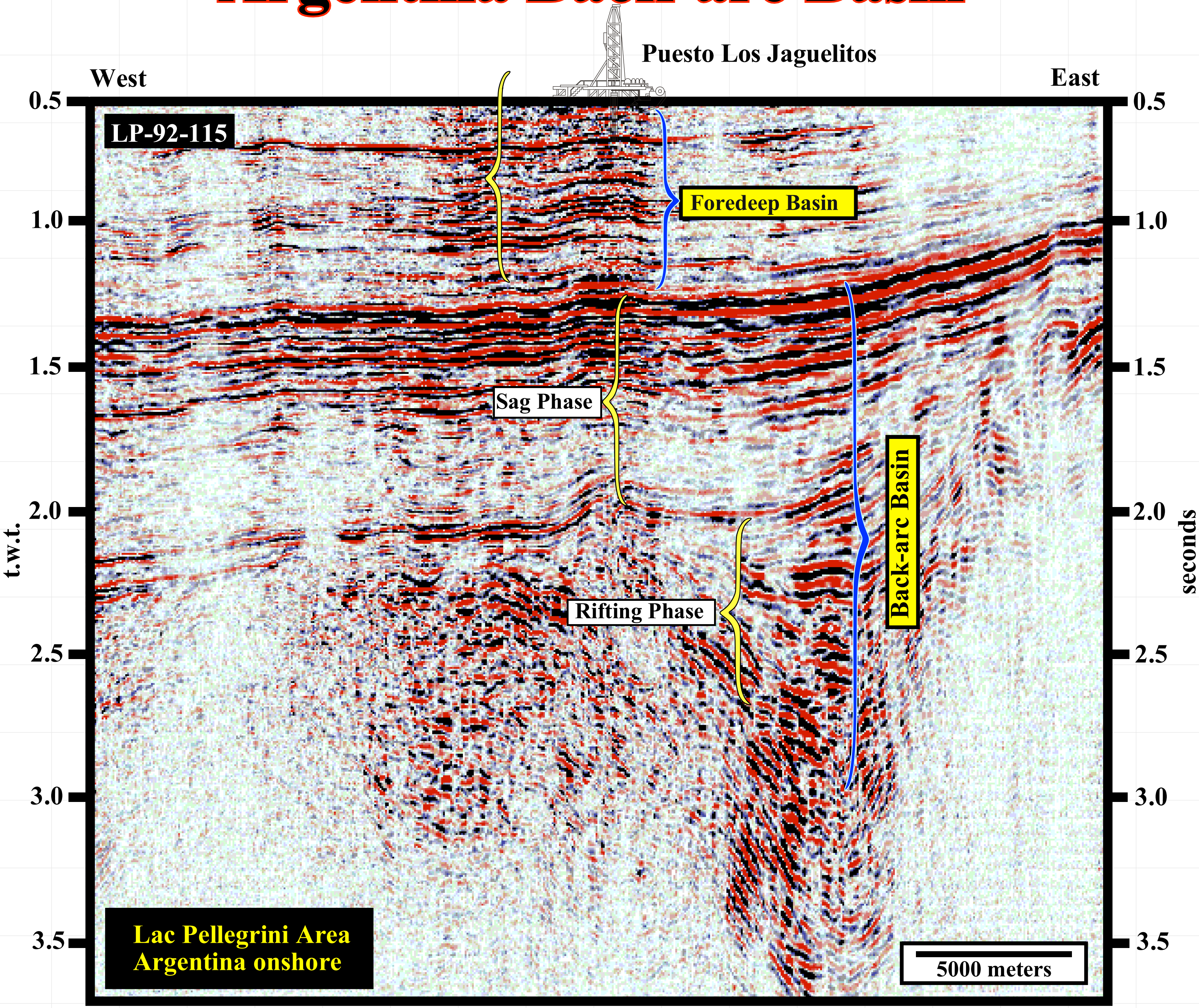
Regional Context

Back-arc basin

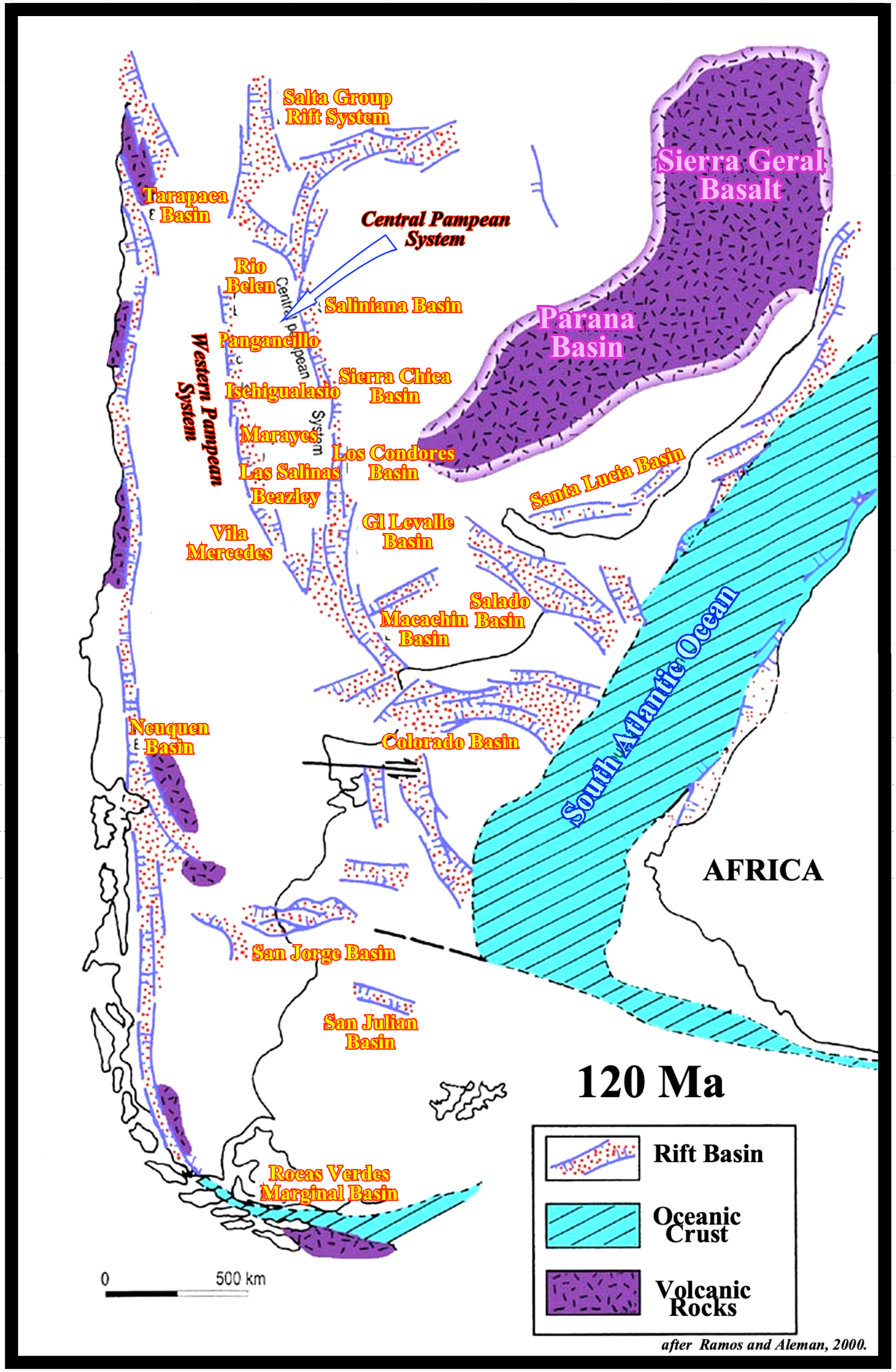


Potential Generating Petroleum Subsystem: Rift basins + Transgressive phase of sag (?)

Argentina Back-arc Basin



Early Cretaceous rifting in South America coeval with the Atlantic opening.



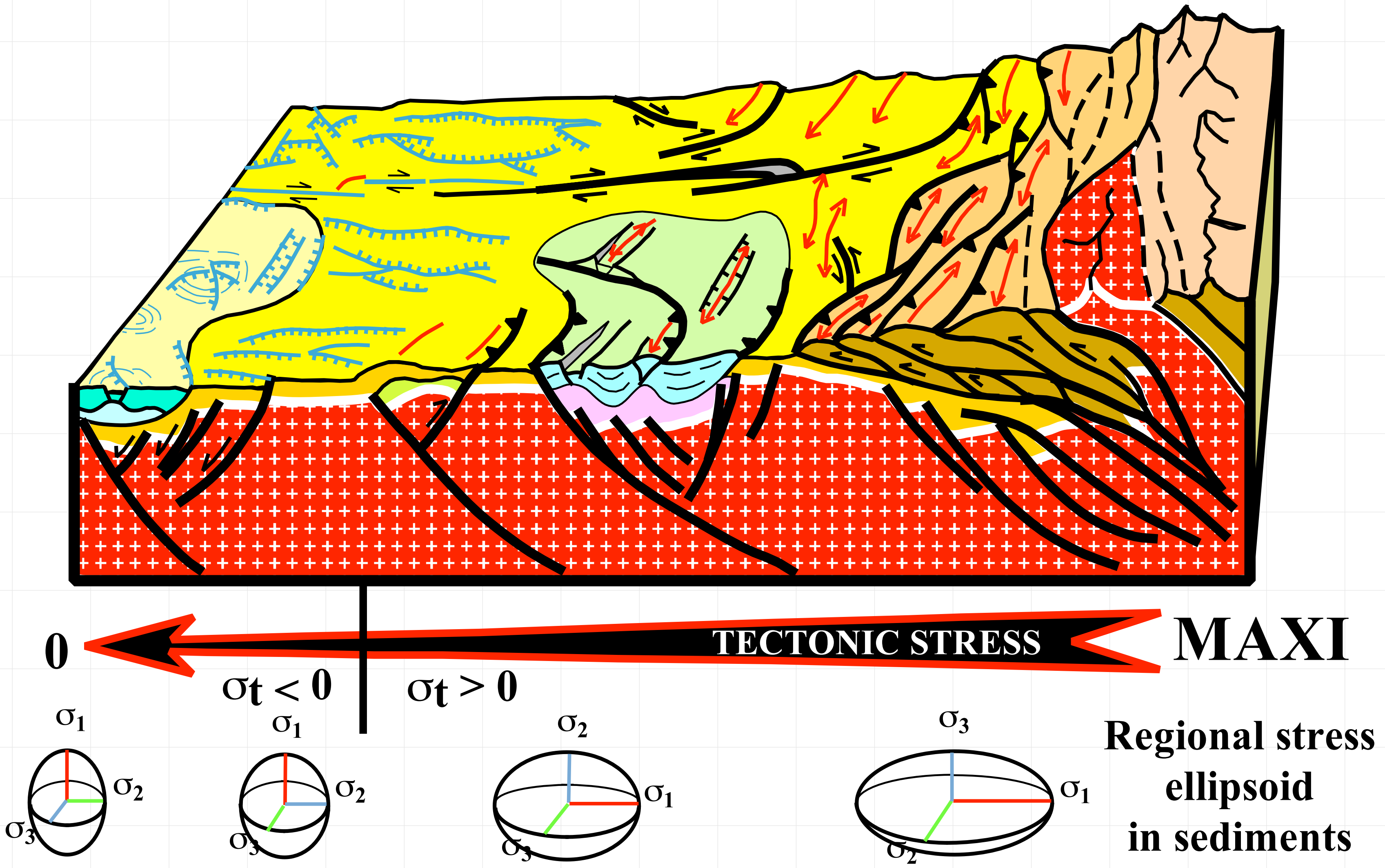
During Jurassic and Cretaceous times a series of complex basins (fore-arc, intra-arc and retro-arc type) developed in the Andes.

This extension is also present in the central Andes and is related in its early stages to the Pangea break-up but later on is associate to a peculiar type of subduction that developed a poorly evolved magmatism (La Negra Formation) with intra and retroarc extension.

In Central Andes extension was active from the volcanic arc in Chile to central Argentina. This extension is coeval with the Salta rift basin and is also responsible of the retroarc basins of Neuquen, Rio Mayo and Magallanes Basin. No oceanic terranes accretion characterizes this period in the central Andes as compared with the Northern Andes.

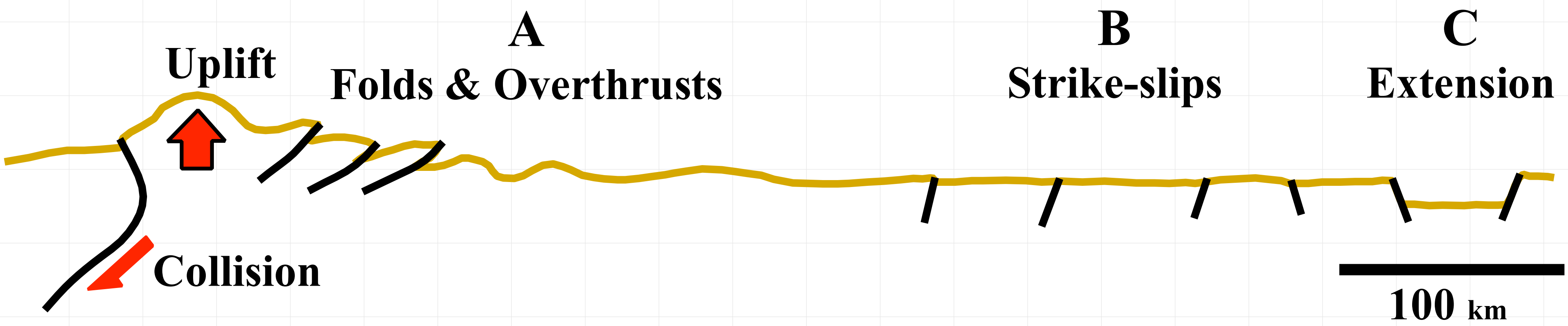
Oblique subduction is responsible for the development of the Atacama strike-slip fault. This fault is parallel to the trench and affected the Coastal Cordillera. It is also responsible of the ascent and emplacement of the arc granitoid of the Coastal Batholith during Jurassic and Early Cretaceous.

Idealized Deformations in Front of Orogenic Belt & Foreland Platform Basins



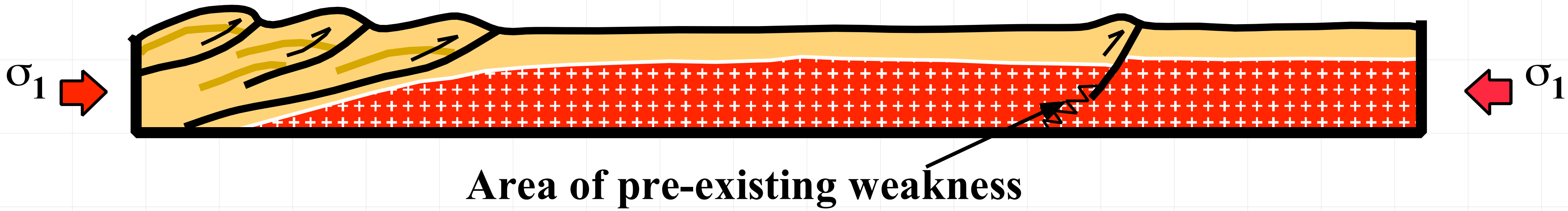
Stress Lessening

σ_2 decreasing



Deformation Tracks

Rigid Bloc Transmits Stresses Without Apparent Deformations



Lateral extension
in
Forelands & Hinterlands

Forelands and Hinterlands (part of a subduction or over-ridding plate) are traversed for hundreds of kilometers by sets of fractures that have caused lateral elongation parallel or sub-parallel to neighboring collisional orogenic margins.

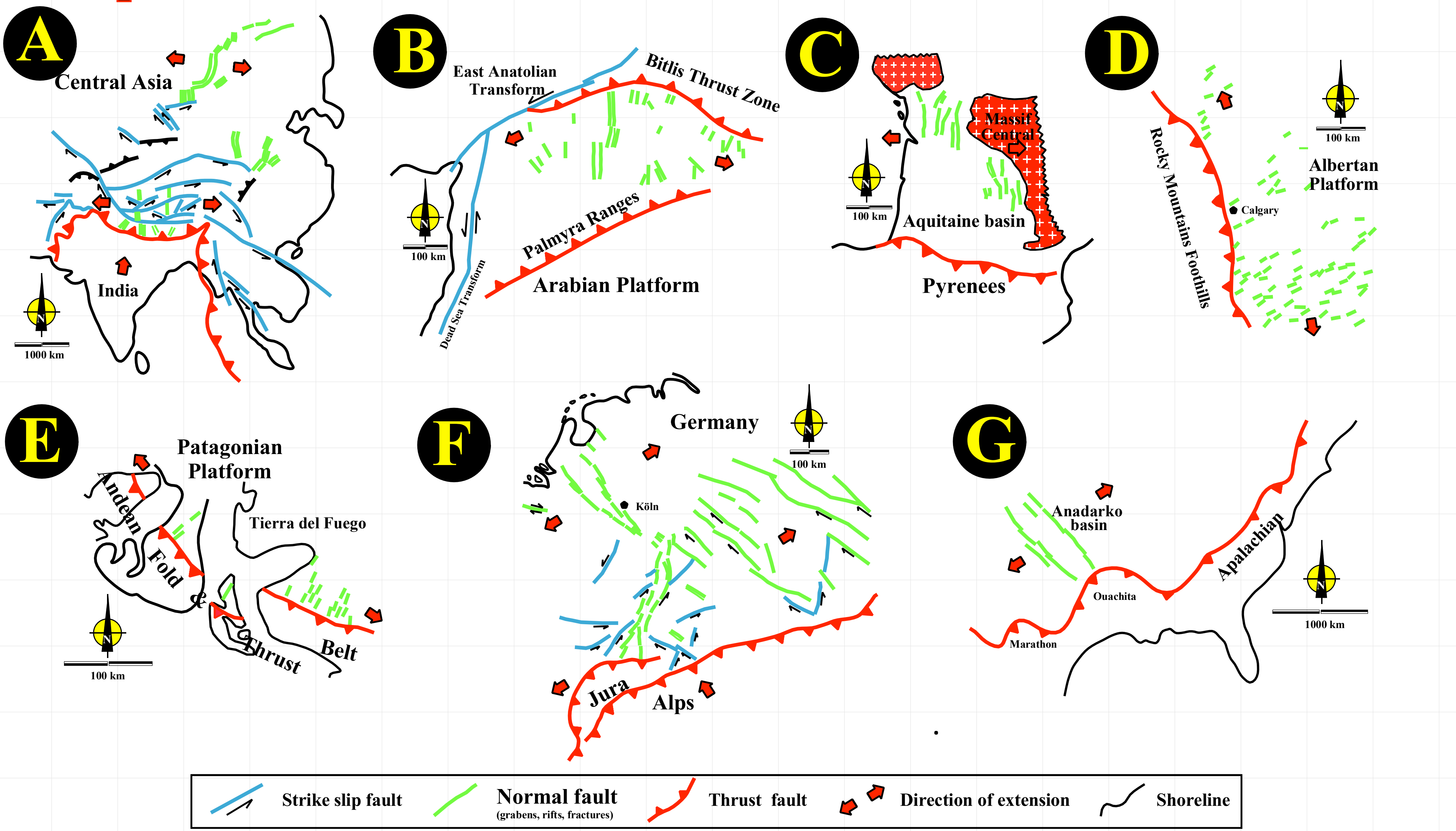
The major proportion of lateral foreland stress is contributed by macrostructures such as grabens and transcurrent faults, whose attitudes may be related to ductile-failure criteria.

These extensional structures, which are approximately coeval of the contractional structures in the neighboring deformation belt, can not be interpreted as allocogeneous as defined by Shatsky, i.e. they are not associated with the opening of an ocean.

Lateral Extension

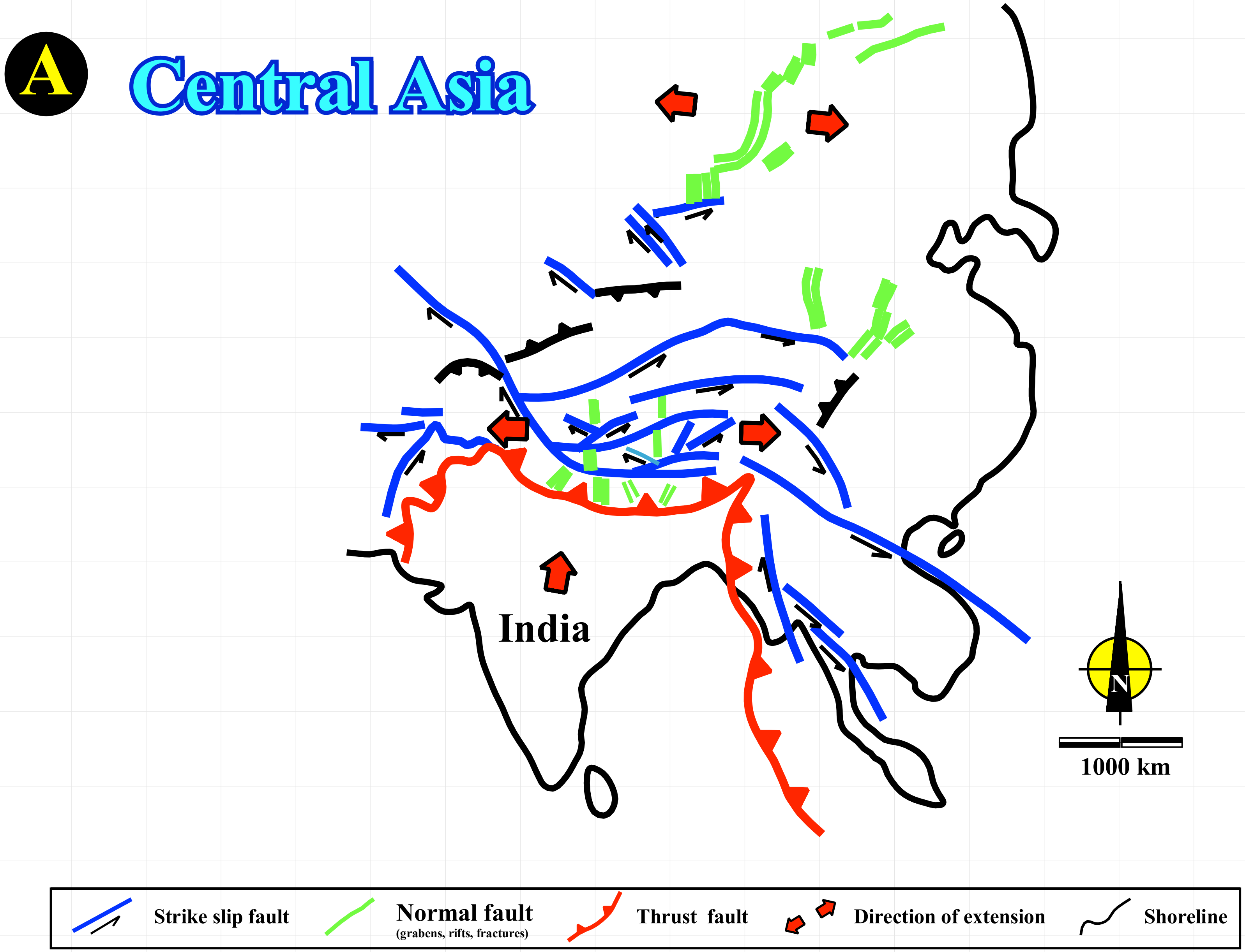
Forelands & Hinterlands

Examples



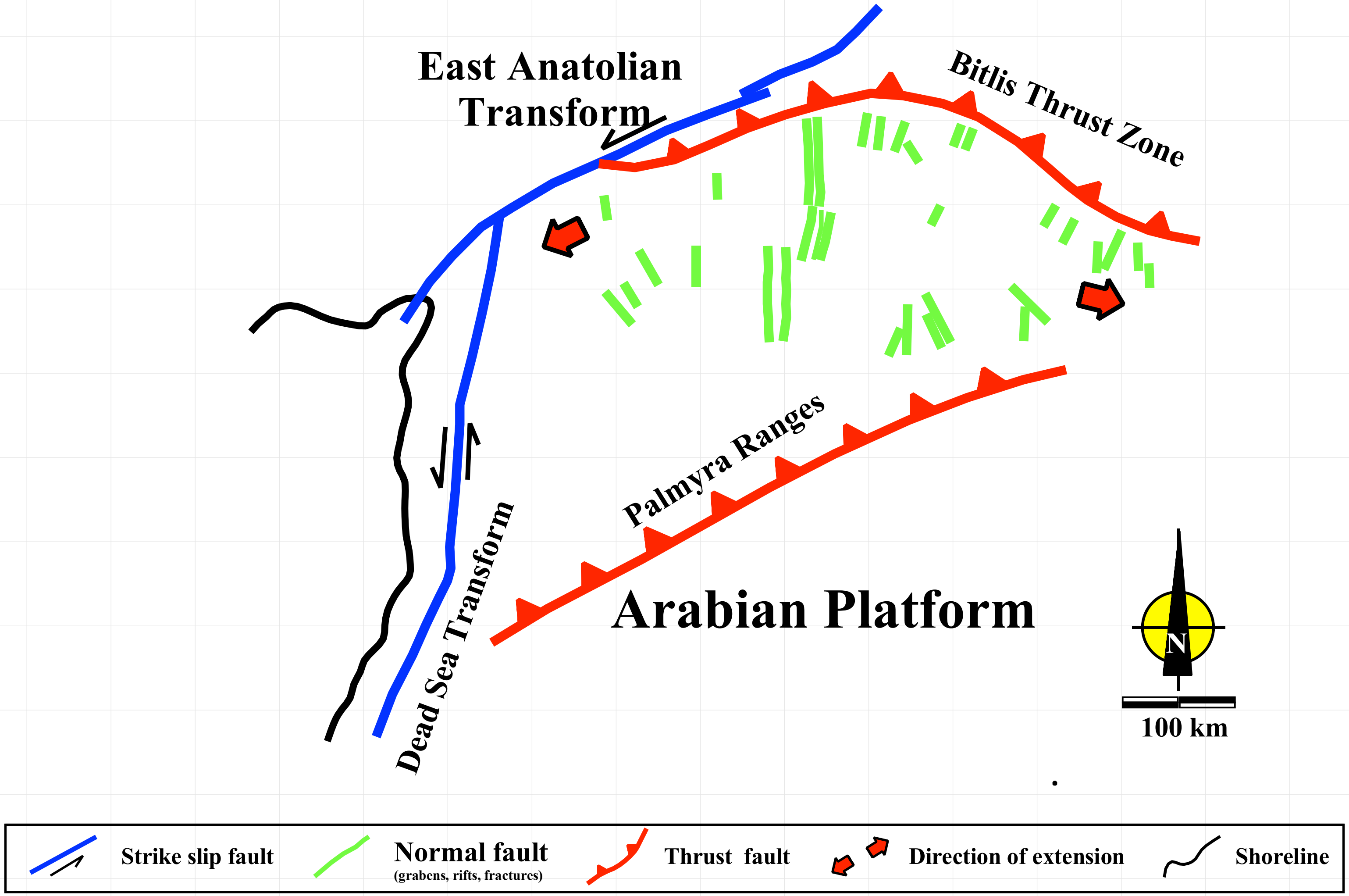
Lateral extension in Forelands & Hinterlands

A Central Asia



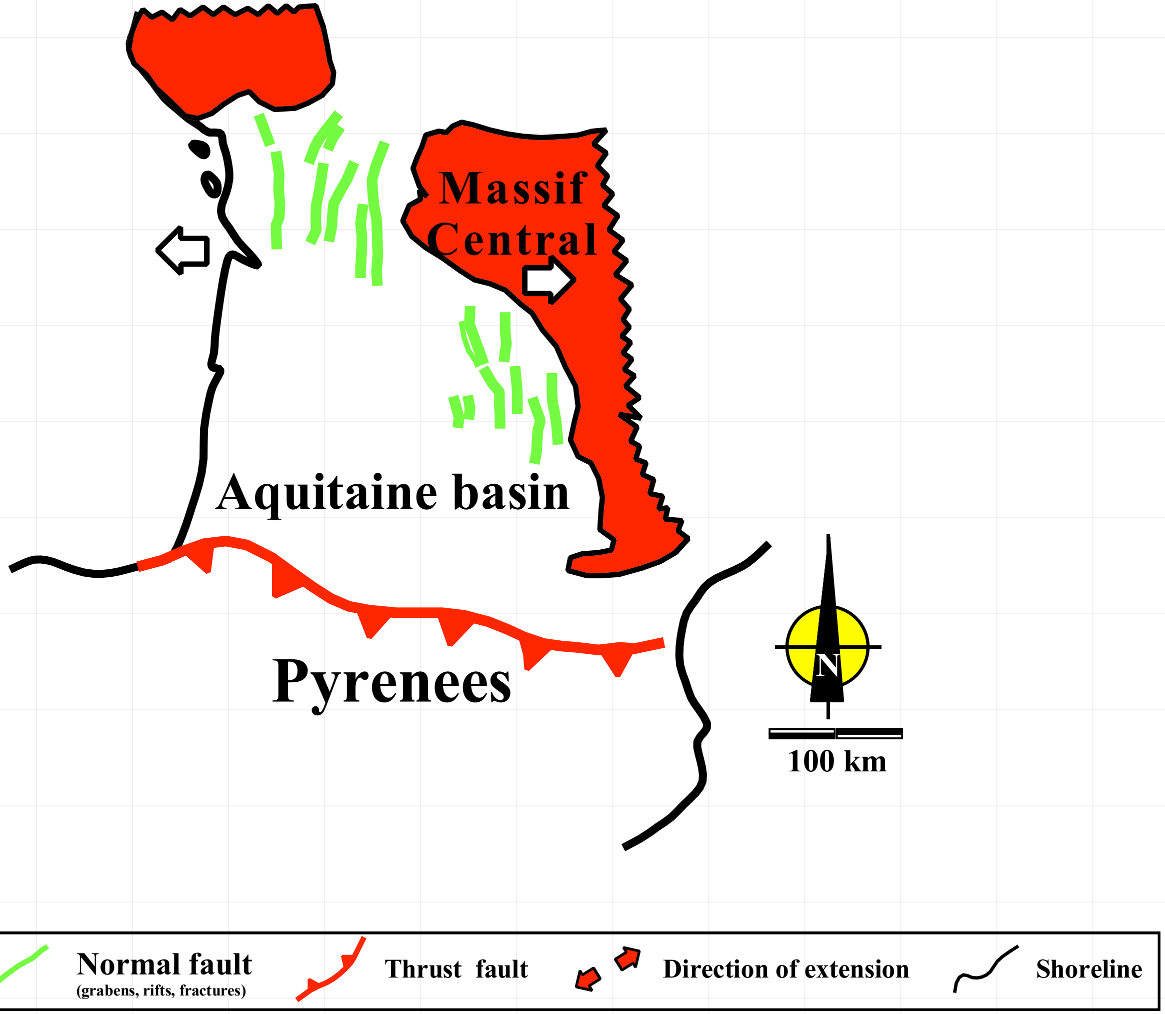
Lateral extension in Forelands & Hinterlands

B Syrian / Turkish foreland



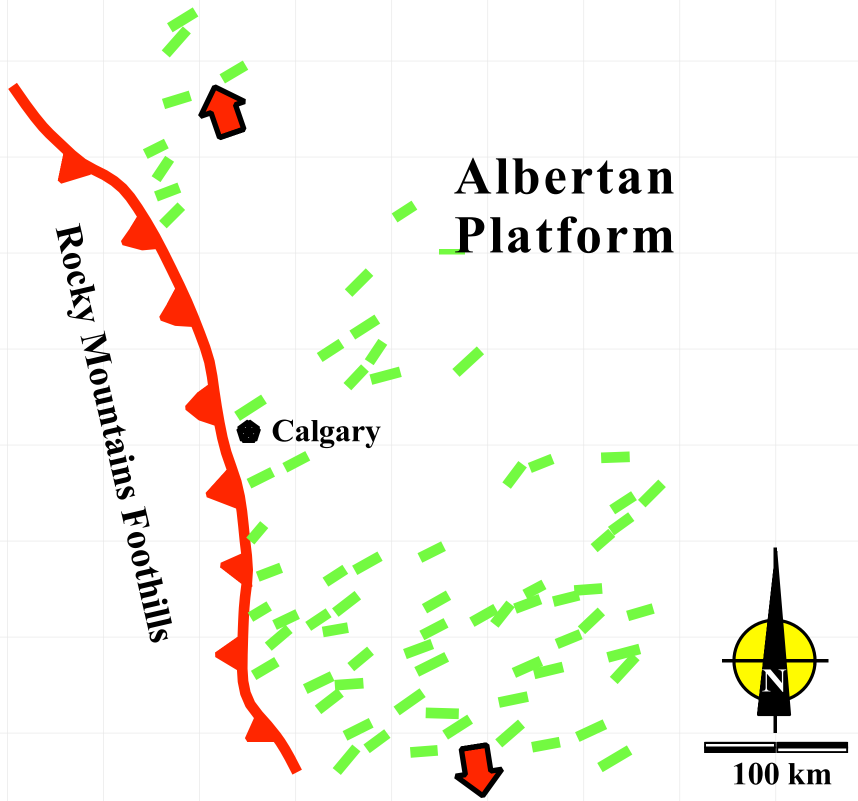
Lateral extension in Forelands & Hinterlands

C Aquitaine basin



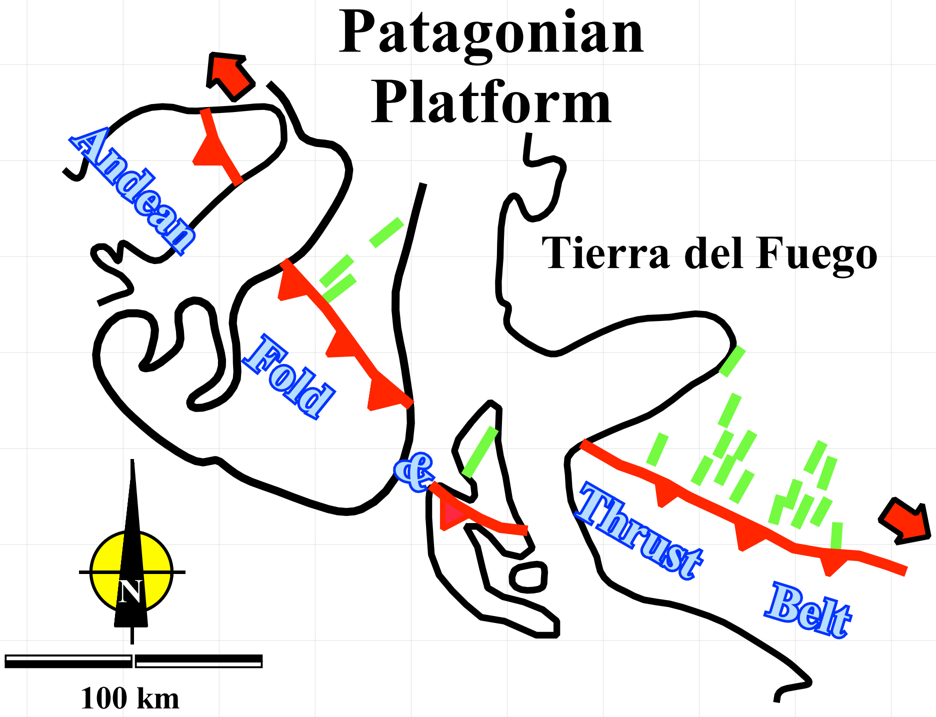
Lateral extension in Forelands & Hinterlands

D Albertan Platform



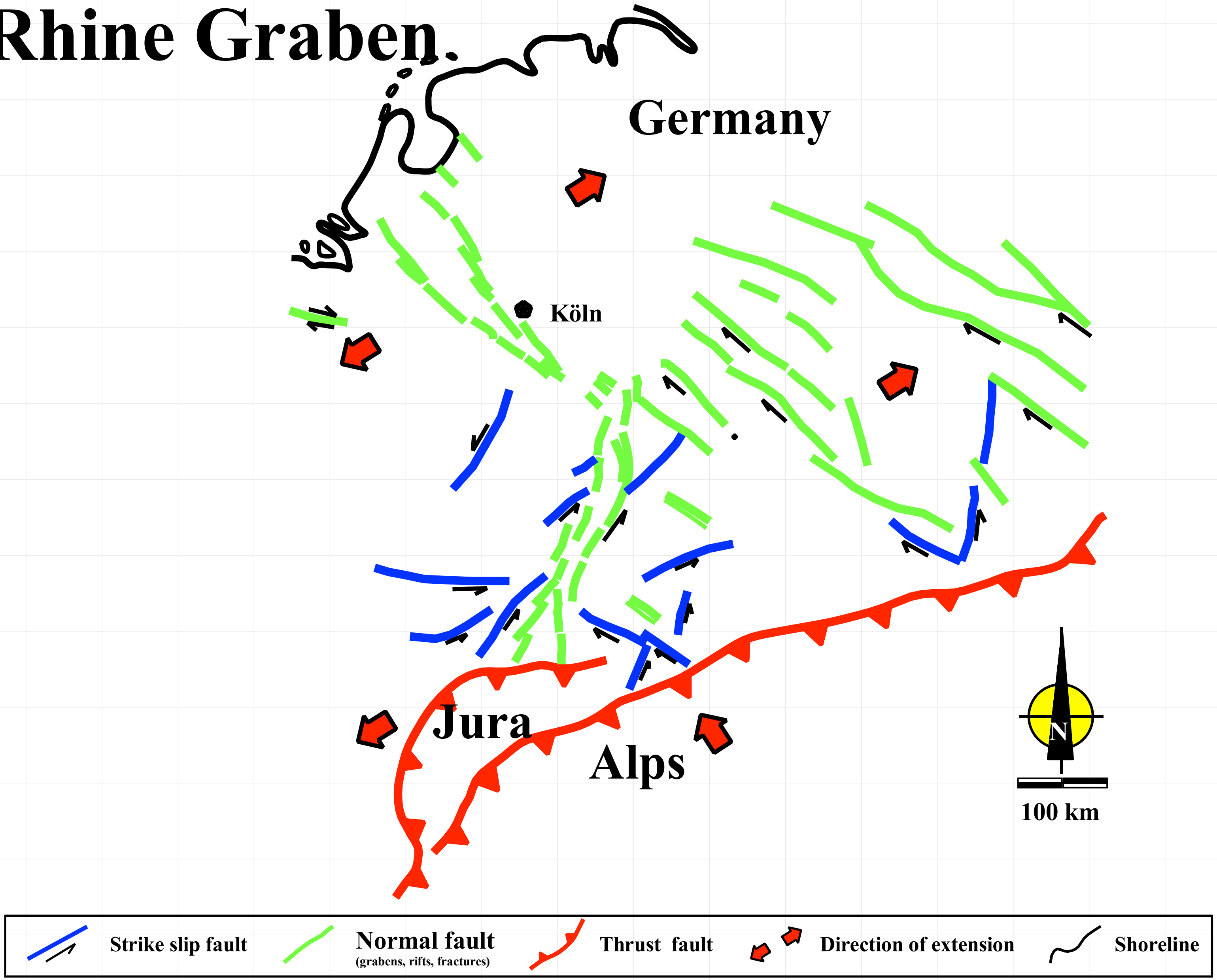
Lateral extension in Forelands & Hinterlands

E Patagonian Platform



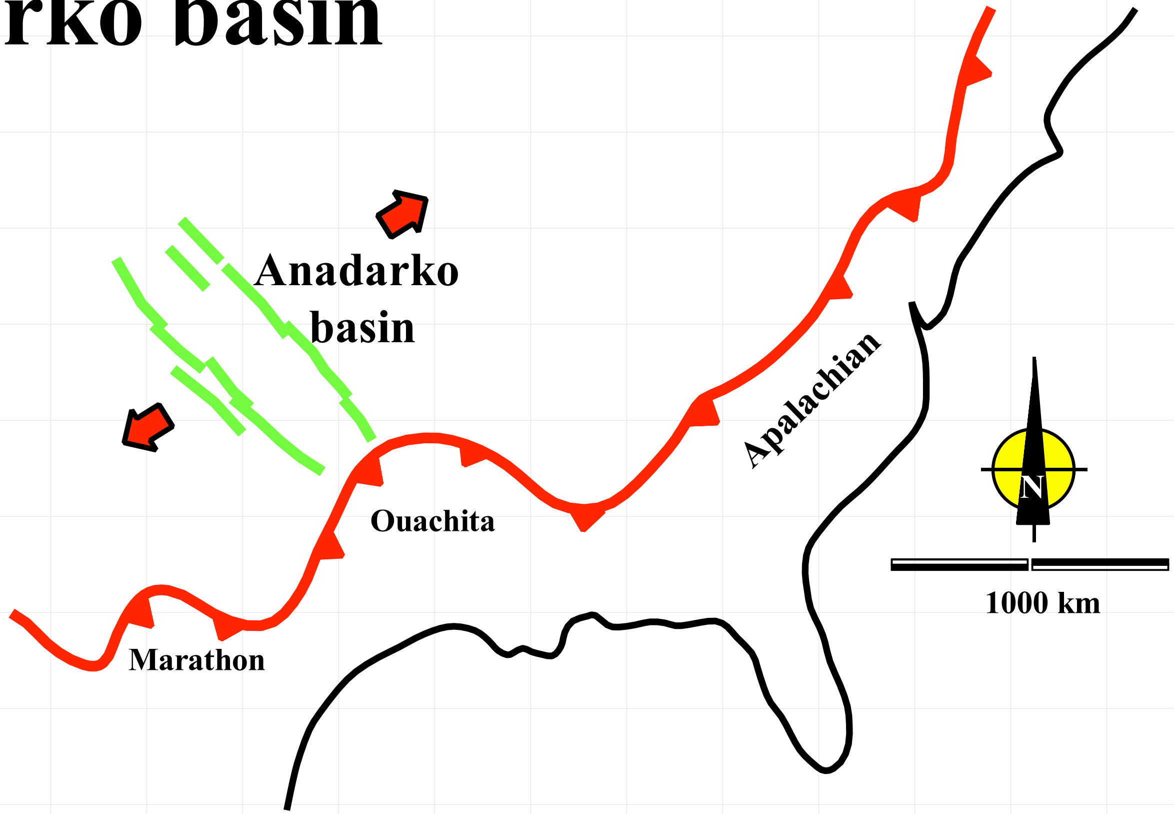
Lateral extension in Forelands & Hinterlands

F Rhine Graben



Lateral extension in Forelands & Hinterlands

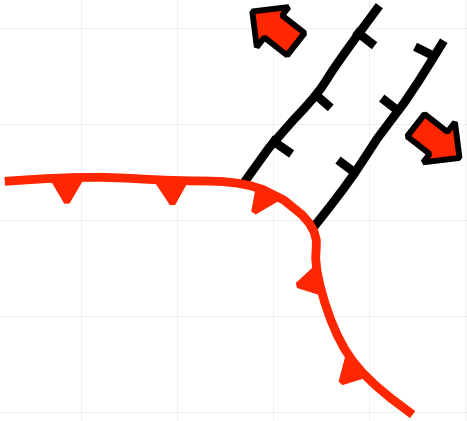
G Anadarko basin



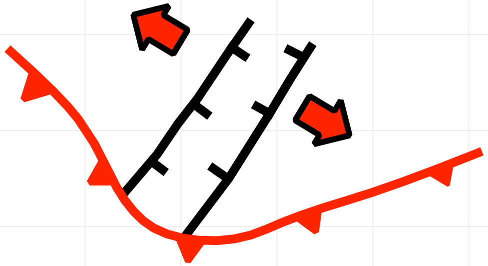
Lateral extension in Forelands & Hinterlands

Macrostructures

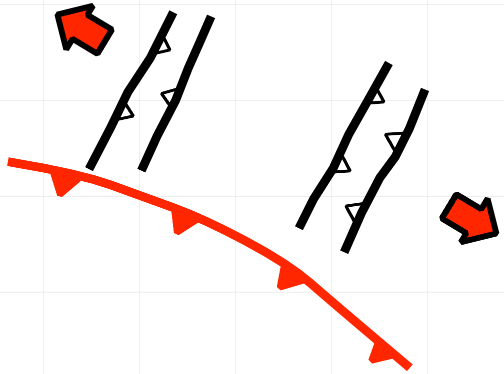
Redrawn from Hancock, P.L. & T,G, Bevan, 1987



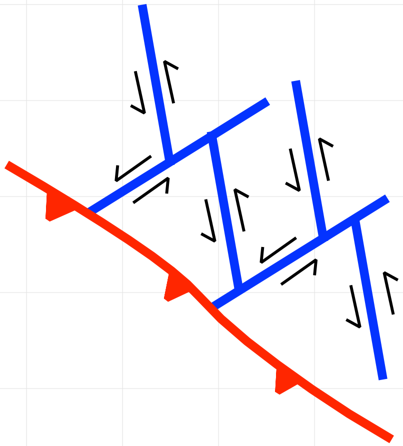
Graben located opposite a salient on the leading edge of a thrust sheet



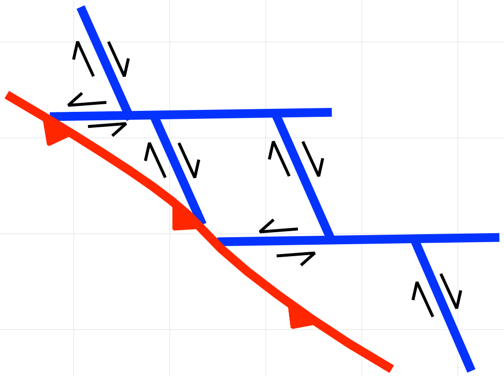
Graben located opposite an embayment on the leading edge of a thrust sheet



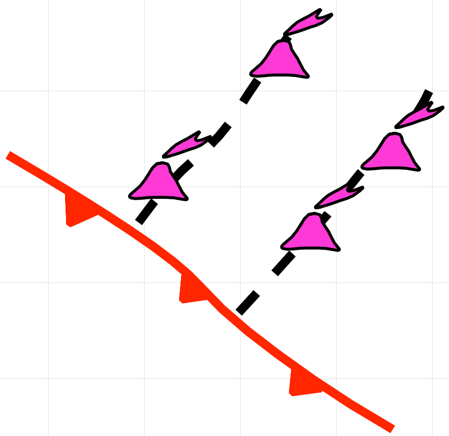
Troughs bounded by inward-facing monoclines



Conjugated brittle strike-slip faults

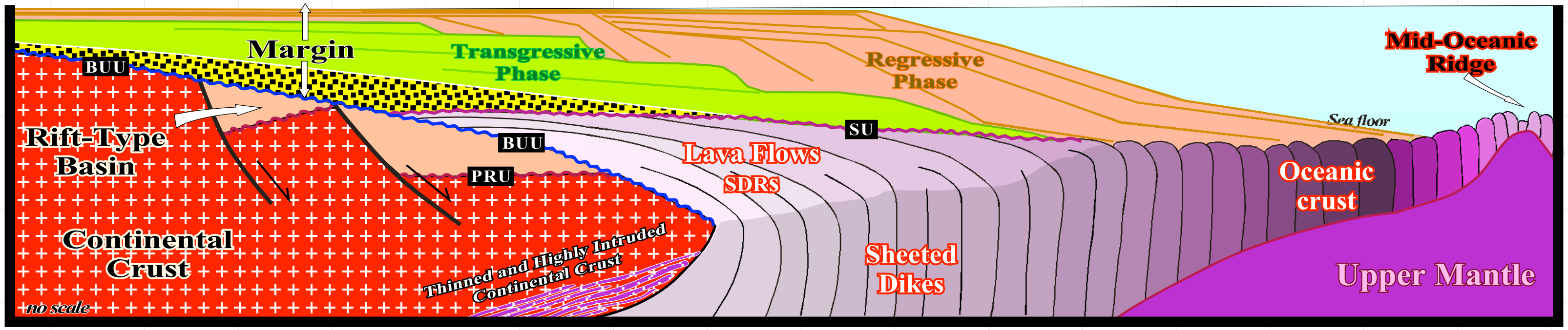


Conjugated ductile strike-slip faults



Fissure eruptions related to dykes

Volcanic Divergent Margins

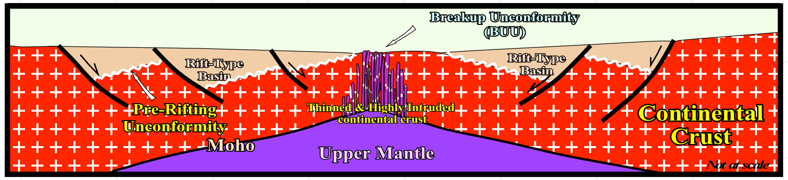


Opening of the South Atlantic Ocean

1- Rifting

(Rift-type basins, volcanism infilling, Pre-rifting Unc.)

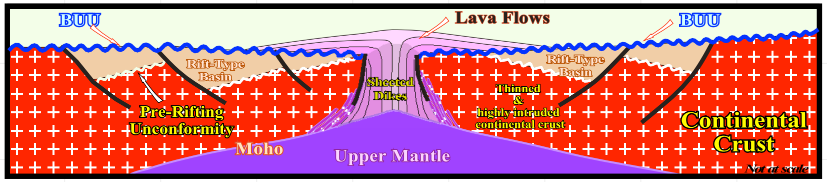
West East



2- Breakup

(lava flows, breakup unconformity BUU)

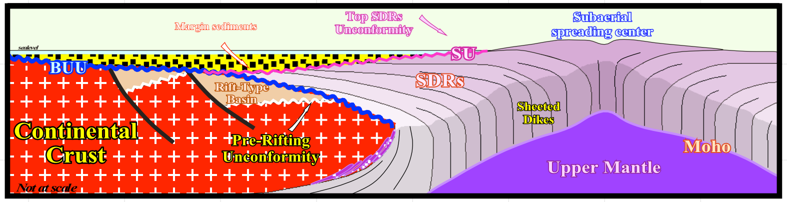
West East



3- Early Drifting

(SDRs, SDRs unconformity SU, proto-ocean)

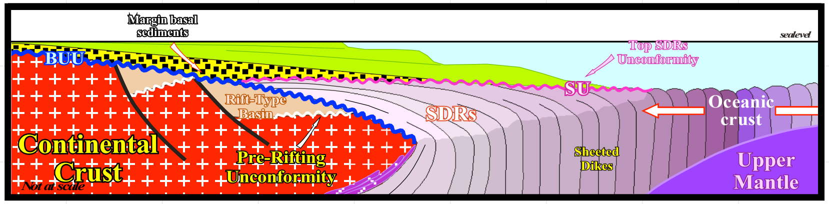
West East



4- Youthfull Drifting

(oceanic crust, transgressive drowning)

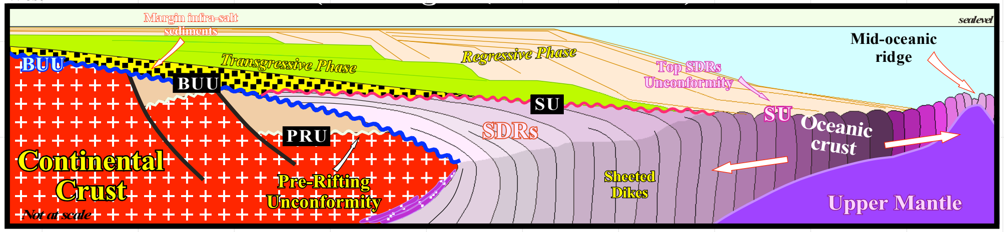
West East



5- Mature Drifting

(regressive phase of the post-Pangea encroachment cycle)

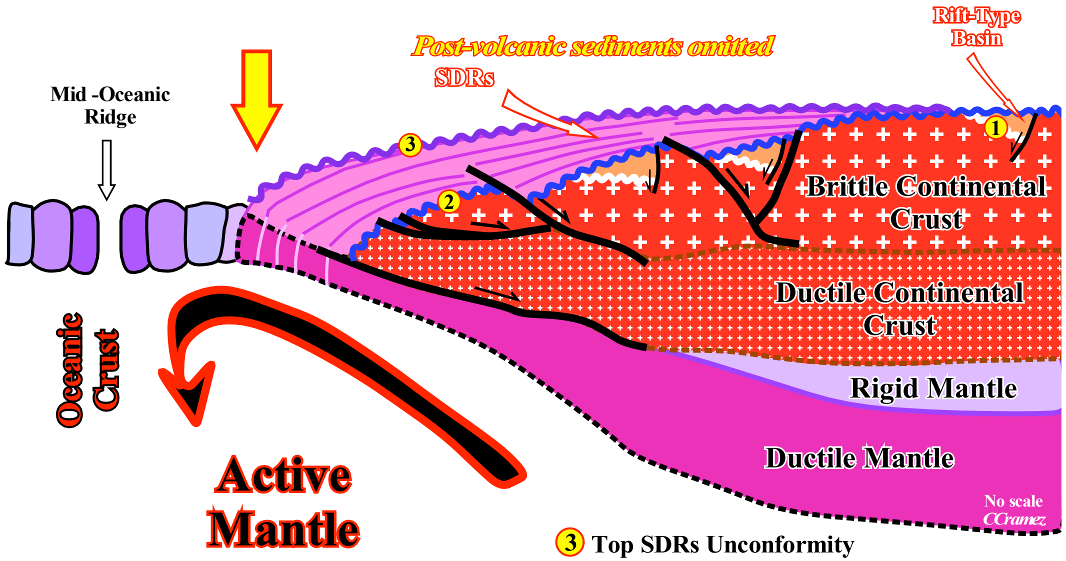
West East



Breakup of the Pangea Lithosphere

1) Active Mantle

Volcanic Divergent Margin

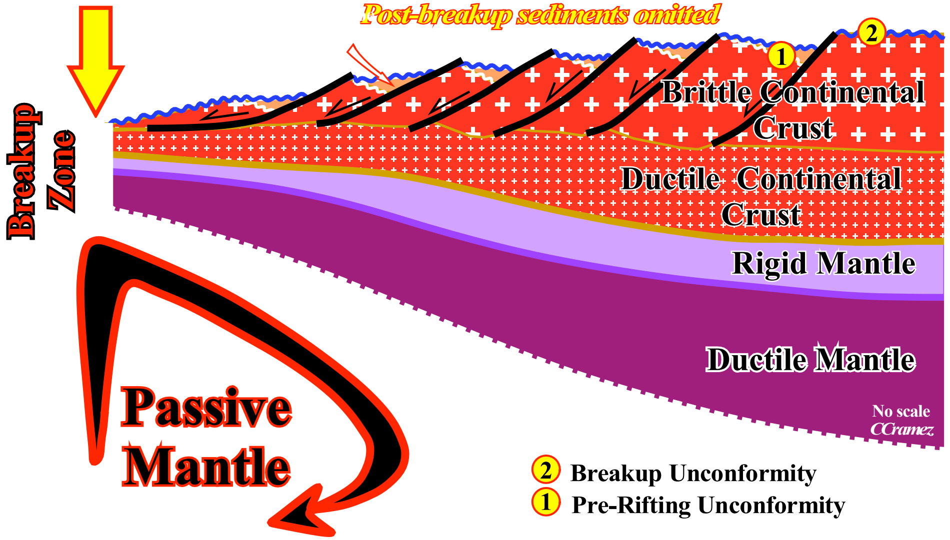


3 Top SDRs Unconformity
2 Breakup Unconformity
1 Pre-Rifting Unconformity

CCramez, modified from http://www.mantleplumes.org/WebDocuments/GeoffroyCRAS.pdf

2) Passive Mantle

No Volcanic Divergent Margin

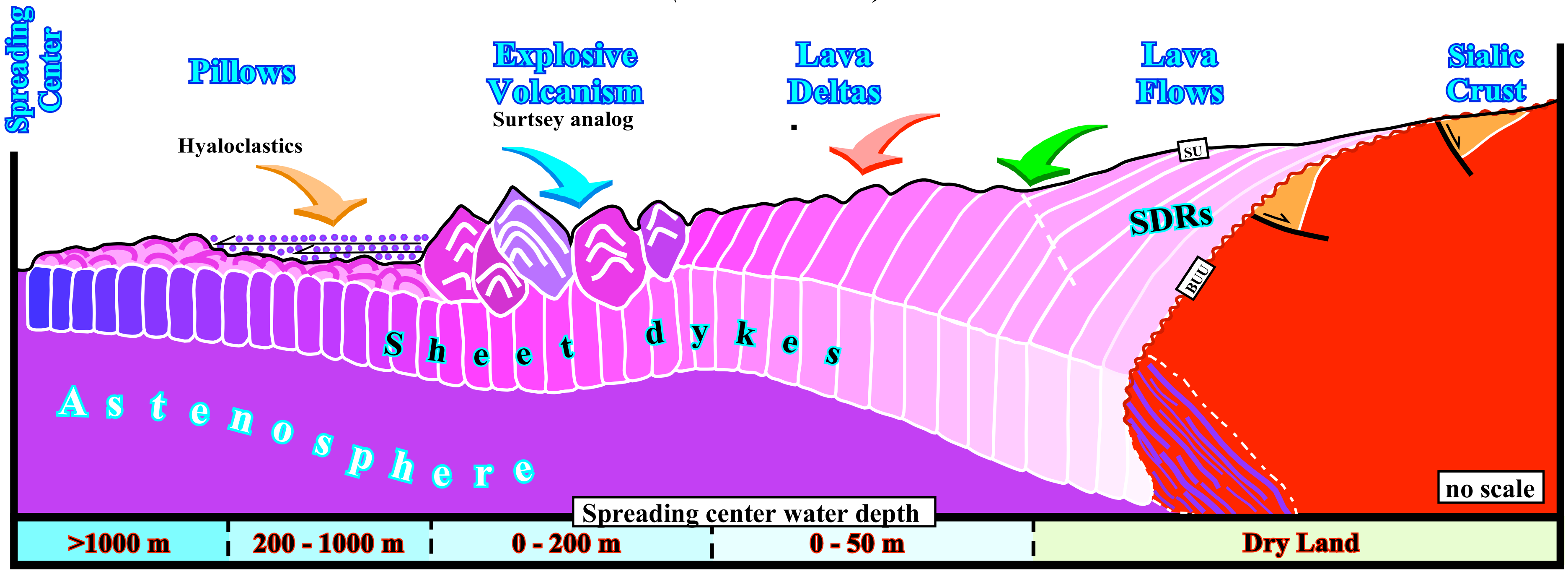


CCramez, modified from http://www.mantleplumes.org/WebDocuments/GeoffroyCRAS.pdf

Basement Evolution Model for Volcanic Margins

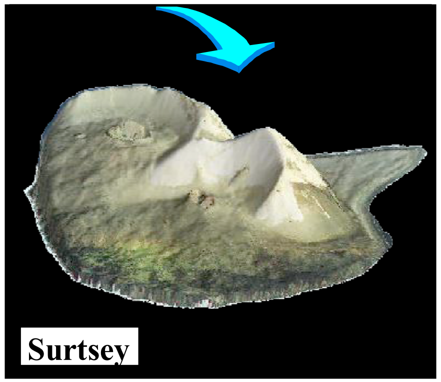
(based on Gulf Coast opening)

(sediments omitted)

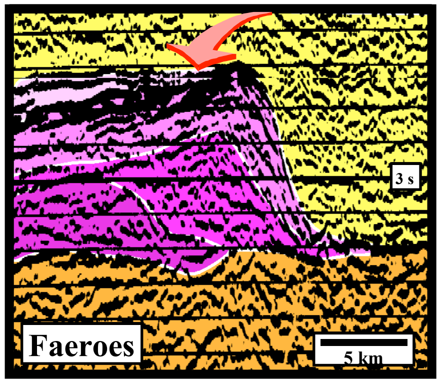


Submarine Ash Plume

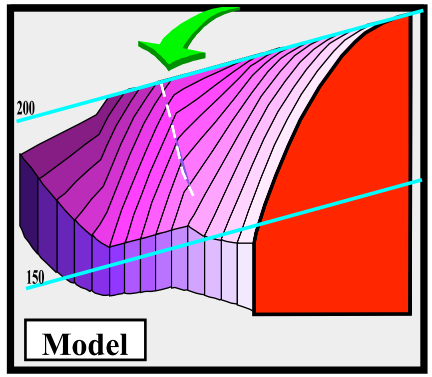
Volcanic Explosion



Lava Deltas (DSDP 163/6-1)

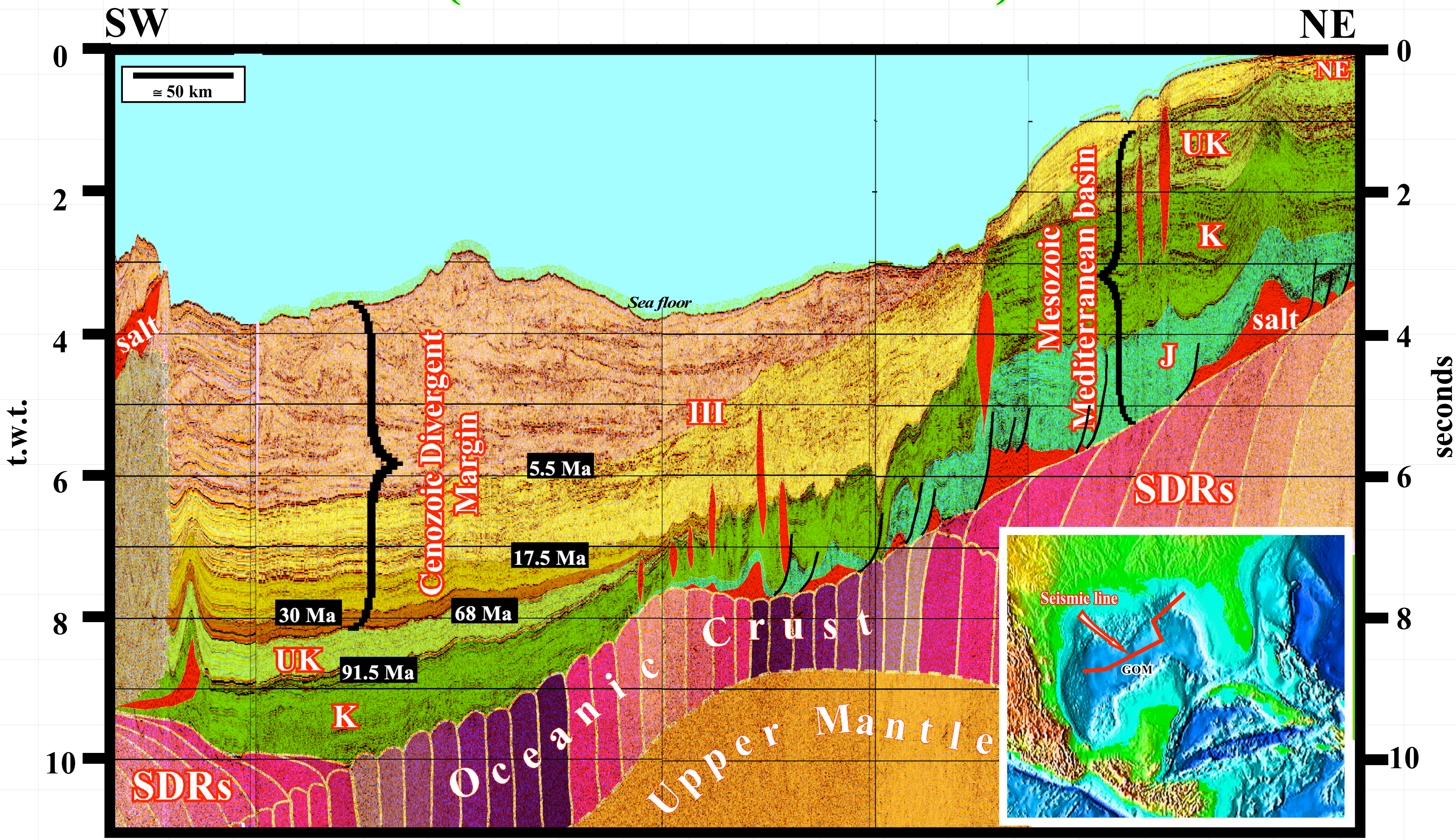


SDR/Lava Delta Boundary



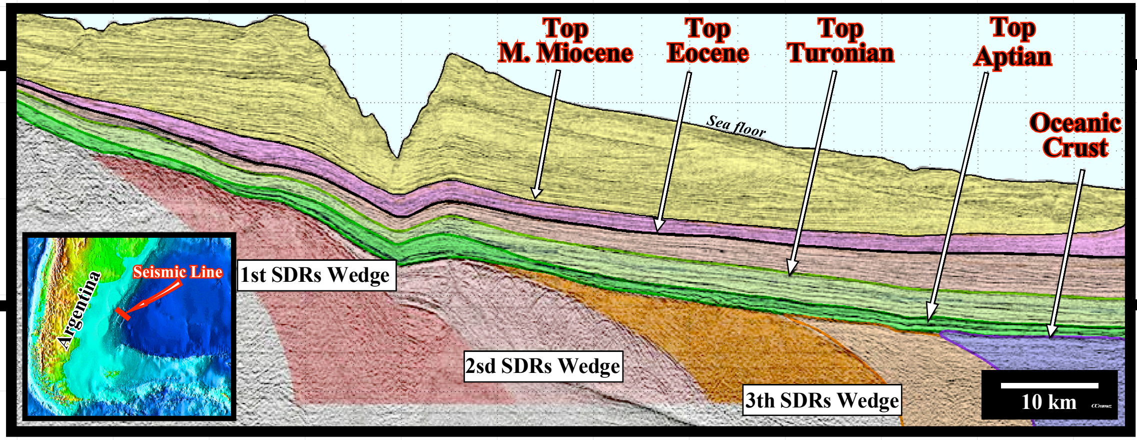
Opening of the Gulf of Mexico

(SDRs & Oceanic Crust)

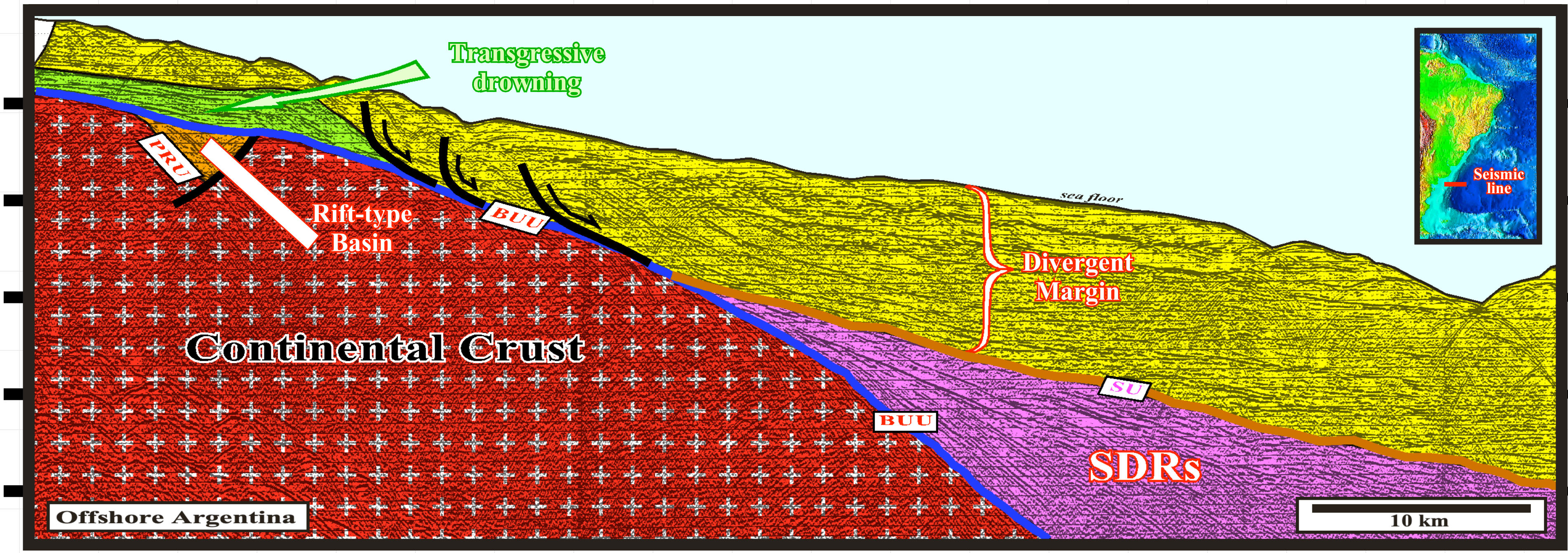


Seaward Dipping Reflectors

(Argentina Offshore)

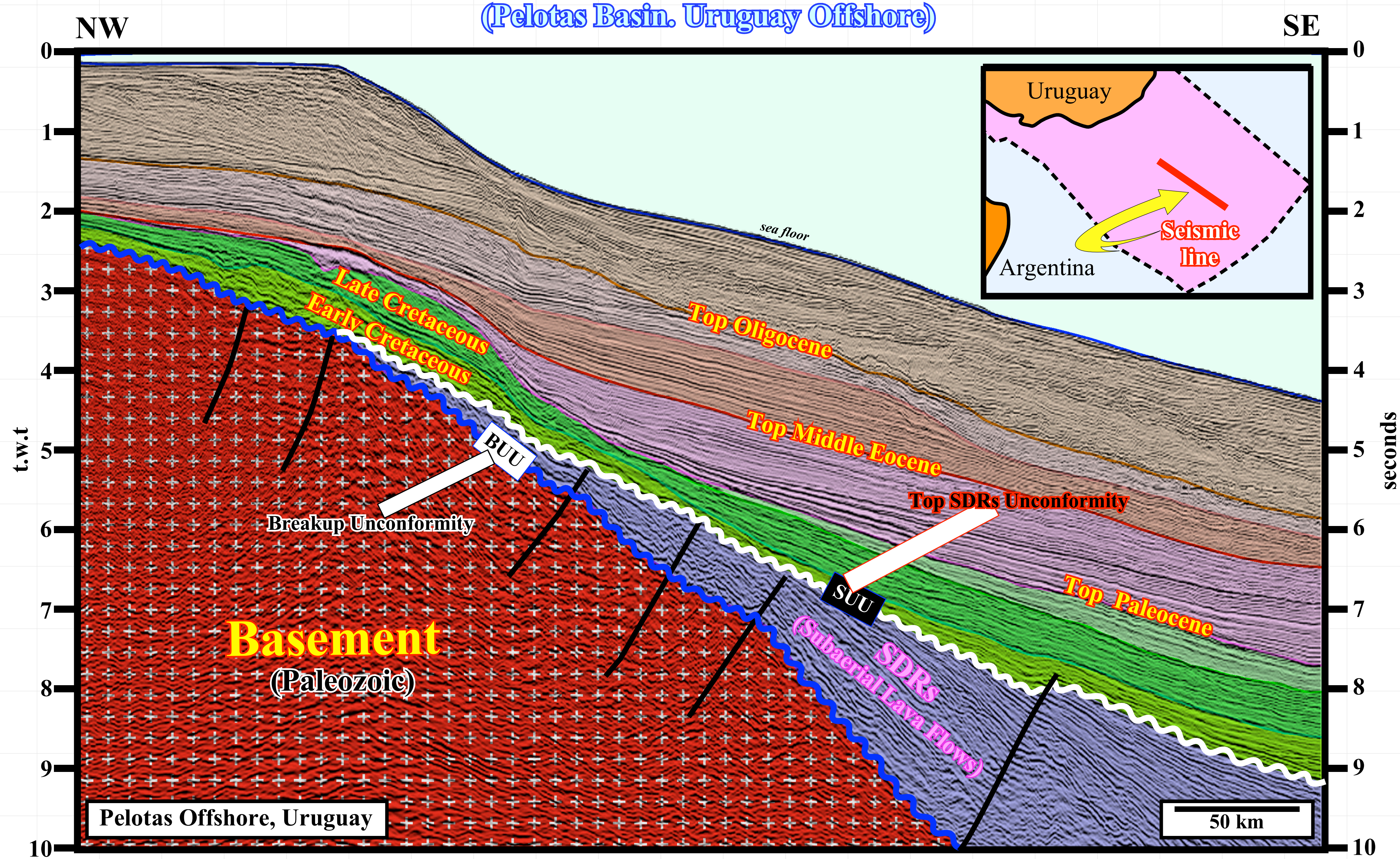


CCramez, adapted from
http://www.mantleplumes.org/images3/ArgentinaFig4_917.jpg



SDRs (subaerial lava flows)

(Pelotas Basin. Uruguay Offshore)



Petroleum System

A Petroleum System emphasizes the genetic relation between a particular source rock and the resulting petroleum accumulation.

A Petroleum System includes all geological elements and processes that are essential for oil and gas deposits to exist in nature.

Basic Elements

(i) A petroleum source rock ;
(ii) A migration path ;
(iii) A reservoir rocks ;
(iv) A seal and trap.

The geological processes that create each of these basic elements.

All these elements must be correctly placed in time and space so that organic matter included in a source rock can be converted into petroleum deposit.

Petroleum System

(i) Source Rock } Generating Petroleum Subsystem

(ii) Reservoir

(iii) Trapping

(iv) Migration

(v) Retention

} Entrapment/Migration Petroleum Subsystem

} Petroleum System

A Petroleum System (PS) exists wherever all the basic elements are known to occur or are suspect to occur.

Successful exploration for producible hydrocarbons in subsurface depends on satisfying the following probabilities :

A) Probability of existence of a trap :

Structure x Reservoir x Seal

B) Probability that the trap has received and physically retained a petroleum charge :

Source x Maturation x Migration Path x Timing x Retention

C) Probability that the entrapped petroleum has been preserved from effects of thermal or bacterial degradation :

Temperature Regime x Meteoric Water Ingress

Since these three main probabilities are interdependent of each other, the overall probability of discovering producible hydrocarbons at a given location is the product of the probabilities of these individual factors. In other words, if any one of these three main factors is zero (0), the overall probability of success is zero (0), regardless of how favorable the other two remaining factors are.

Petroleum System

Most classifications and studies of sedimentary basins, mainly, concern the structural behavior of the sediments within them. They often forget any relationship with hydrocarbons that may be encountered. The classification we followed is based on the new paradigm of modern geology - Plate Tectonic Theory -. This hypothesis explains, largely, the subsidence and eustatic variations. They are primarily responsible for the space available for sediment. These geological data improve our approach and evaluation of the petroleum parameters:

(i) Petroleum Potential (mature source rocks) ;
(ii) Reservoir-rock (presence and petrophysical characteristics) ;
(iii) Trapping (trap and sealing) ;
(iv) Feeding (migration and age compared to the age of trapping) ;
(v) Retention.

for each of the different types of sedimentary basins in question, which is essential to the study of petroleum systems. However, as the authors of this classification (Bally and Snelson, 1980) it is said: "The classification of basins does little to improve our hydrocarbon volume forecasting ability".

The prediction and evaluation of hydrocarbons in sedimentary basins is much better approximated by studying the Petroleum System, in other words by the study of genetic relationships between a particular source-rock and the hydrocarbon accumulation associated (L.B. Magoon, 1988) in this sense, it is very important not to forget that hydrocarbon exploration by the study of petroleum system involves that a number of assumptions and geological principles are scrupulously respected. Based on the geochemical correlation between the petroleum and rock-mother (known or potential), L. B. Magoon subdivided the petroleum systems in three main families that emphasize three levels of certainty:

A) Known Petroleum System (.)

A petroleum system is known when there is a good geochemical correlation between the accumulation and source-rocks. Ex: La Luna / Aguardiente (.) petroleum system in the back-arc basin of Lake Maracaibo.

B) Hypothetical Petroleum System (!)

A petroleum system is hypothetical when geochemical data are sufficient to identify the source-rock, but without a geochemical correlation (biomarkers) between the sorce-rock and the potential accumulations. Ex: The Agua / Cauderalito Clara (!) petroleum system (.) in the Falcon basin (onshore northern Venezuela).

Petroleum System

C) Speculative Petroleum System (?)

A petroleum system is speculative when the occurrence of a source-rock and accumulations are possible, or probable, based on geological and seismic surveys, but without geochemical evidence. Ex: The petroleum system Kimmeridgian Shales / Tertiary Sandstones (?) in Kaithanimbar basin (Eastern Indonesia) .

In the case of Known Petroleum Systems (.), the explorationist does not need to rely on the classification of basins followed here because, by definition, a known petroleum system is necessarily associated with a mature sedimentary basin tor with an overmature at the standpoint of petroleum exploration.

For the study of Hypothetical Petroleum Systems (!) and moreover for the Speculative Petroleum Systems (?), it is essential that explorationists have a good geological knowledge not only of the sedimentary basin, but also the infrastructure. Such knowledge must take into account the geological evolutions in space and time. That it is why, as said have said before, the original classification of Bally and Snelson was slightly changed.

We note again that the classification followed here did not claim to classify the different sedimentary basins according to their hydrocarbon wealth. It classifies them, in time and space, on the base of their position relatively to the megasutures and depending on the origin of the subsidence. Recall, secondly, that any basin whose thickness is less than 1000 m is excluded on the Bally's classification. We can say that as the basins are not classified according to their structural style, the followed classification is very conducive to the study petroleum systems because, indirectly, it takes into account paleogeographic, paleoclimatic and paléogéothermal considerations. It explains, relatively better than all other classifications the distribution of certain source-rocks, especially the marine source-rocks associated with the transgressive phases of continental encroachment stratigraphic cycles :

- Ulmichek and Klemme (1990) reported that about 75% of global oil reserves and 60% of gas reserves are associated with source-rocks of the Upper Jurassic and Middle Cretaceous.
- These source rocks parent peak the transgressive phase of the continental encroachment post-Pangaea stratigraphic cycle.
- During the transgressive phase, the eustatic level rose as the volume of ocean basins has decreased as a result of seafloor spreading that accompanied the dispersal of continents that were individualized after the breakup of the Pangaea.
- More than 60% of global oil reserves known today were generated by the source-rocks deposited in association with the Middle Turonian downlap surface, i.e., MFS 91.5 Ma, that is to say, the major downlap surface of the Meso-Cenozoic continental encroahment cycle (post-Pangea).

Petroleum System

All these geological data, which largely control the spatial and temporal distribution of the source-rocks are contained in the adopted classification:

a) The sedimentary basins of western South America considered in most classifications (structural style) as foredeep basin or foreland are here considered as a vertical superposition of several sedimentary basins:

- Rift-type basins, in the Jurassic;
- Back-arc basins, in Cretaceous and Early Tertiary and
- Foredeep basins, since the Late Tertiary.

b) The source-rocks are associated with the Meso-Cenozoic transgression held in the volcanic back-arc basins and not to the tectonic regimes.

c) In most of the examples cited by Demaison (Demaison and Huizinga, 1991) to illustrate the hydrocarbon reserves, the distribution of source-rocks is, totally, independent of the structural style. It is dependent on the geological history of sedimentary basins, which underlines the need to classify sedimentary basins through time and space :

(i) For the foreland basins of the Andes, the petroleum potential is directly related to the Mesozoic back-arc basins and not to Late Tertiary basins (foredeep basins).
(ii) For the Brazilian offshore basins, where hydrocarbon wealth is very uneven (more than 65% of the reserves are located in the Campos and Santos Basin), the proposed classification is consistent with the petroleum systems. Brazil offshore, as elsewhere West Africa offshore, is the result of the temporal and spatial superposition of two different types of basins.

A) The source-rocks associated with the transgressive phase of the post-Pangea continental encroachment cycle have not been enough buried for their organic matter reaches maturation.

B) The potential generating petroleum subsystem is formed by the lacustrine hypersaline rocks lake rocks (part of Lagoa Feia formation).

- These source-rocks were deposited at the beginning of the divergent margin under the evaporites.
- The sediments filling the rift-type basins, unlike those of the West Africa, seem do not have too much oil potential.

Petroleum System

d) For the carbonate platforms, Demaison and Huizinga (1991) report that the difference in hydrocarbon wealth between Campeche-Reforma and Florida basins, who have just the same structural style, is due to variations in the quality of source-rocks and geothermal etting. Although they have a very similar tectonic styles in the classification we have adopted, they belong to very different classes.

(i) The basin of Campeche-Reforma is, during the Mesozoic, as that of Maracaibo, a back-arc basin.

- A priori, it has, therefore, a priori geometry and thermal flux quite high, which are very favorable to the development of mature source-rocks, even if the buring is limited.

(ii) The Florida basin is associated with the North Atlantic divergent margin.

- The source-rocks with oil potential are probably associated with the transgressive phase of the continental encroachment cycle.
- The underlying Triassic rift-type basins, do not have oil potential.
- The potential source-rocks are not very thick (except in some small depocenters in the platform), but also they are not too buried to generate hydrocarbons.

In conclusion, we believe that the classification adopted here in conjunction with a sequential analysis, and in particular with the detailed study of the different stratigraphic cycles (continental encroachment cycle, continental encroachment subcycles, sequence cycles and sequence paracycles) are essential tools for the identification and evaluation of the various petroleum systems : dynamic physical-chemical systems, which change in space and geological time, and which are able to generate and concentrate hydrocarbons.

This definition (Demaison and Huizinga) implies that a petroleum system is composed of two major subsystems: (i) A generating petroleum subsystem, which products hydrocarbon for a certain time interval of geological and (ii) A migration-trapping petroleum subsystem, which concentrates or dispersed hydrocarbons generated from mature source-rocks. If in given sedimentary basins there is no generator petroleum subsystem, the study of the migration-trapping petroleum subsystem becomes superfluous, which is often overlooked by many explorationists.

Three geological factors control the hydrocarbon accumulations in surface:

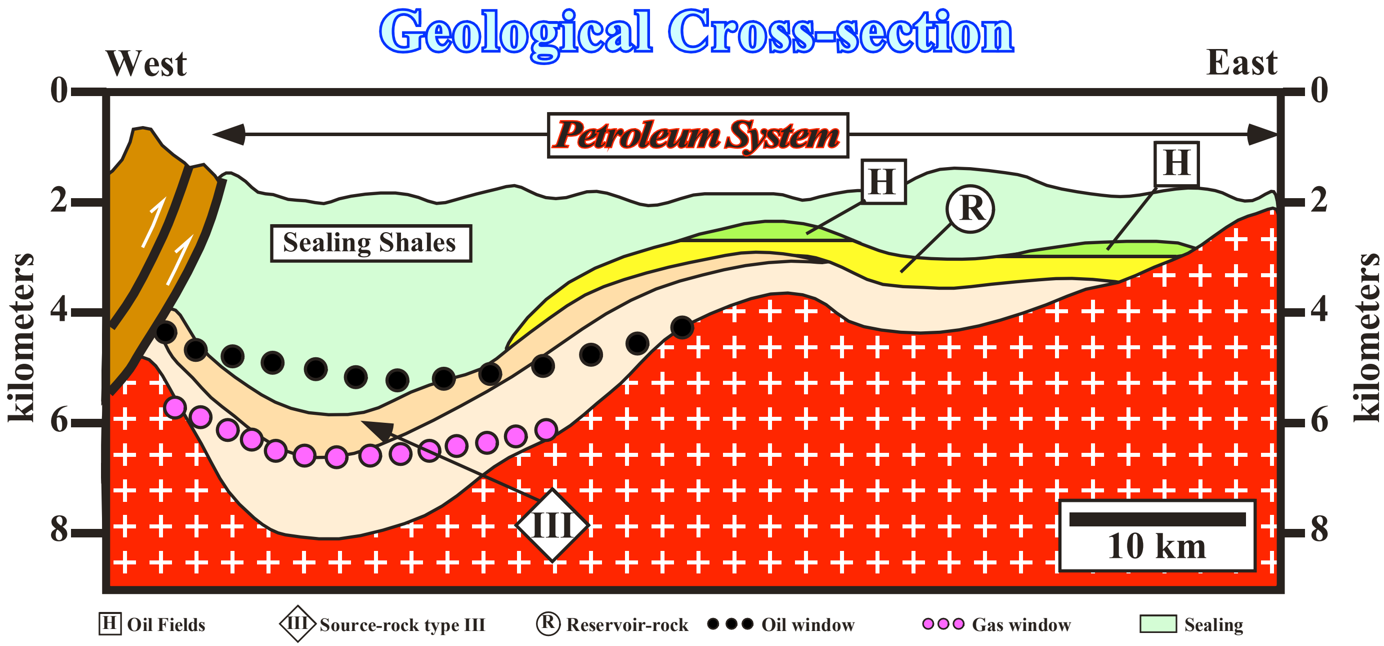
a) A major volumetric generation of hydrocarbon during or after the formation of traps .
b) A favorable geometry migration path, that is to say, the migration routes that lead to the concentration of hydrocarbons in stratigraphic or structural traps rather than a dispersion or loss on the surface.
c) The existence of volumetrically valid traps able to retain oil after feeding.

Petroleum System

The term "volumetrically valid" implies not only an important area closed but the reservoir-rocks with acceptable petrophysical characteristics as well. These geological factors are mapped in space and time so that explorationists can correlate the petroleum parameters that compose oil is a petroleum system, i.e: (i) Source-rock , (ii) Reservoir-rock , (iii) Sealing-Rock ; (iv) Migration ; (v) Trap ; (vi) Retention.

Mapping a Petroleum System

To better illustrate the maps that define a petroleum system, I will take a schematic example derived from B. Magoon (1988).



1) Geochemical Correlation

The first step in the identification of a petroleum system is the establishment of a genetic relationship, a comprehensive geochemical study (including biomarkers), between the hydrocarbons encountered in surfacee or subsurface with potential source-rocks. This is to better understand the rocks that make up the generating petroleum subsystem that is to say, the recognition of the potential source-rocks.

Petroleum System

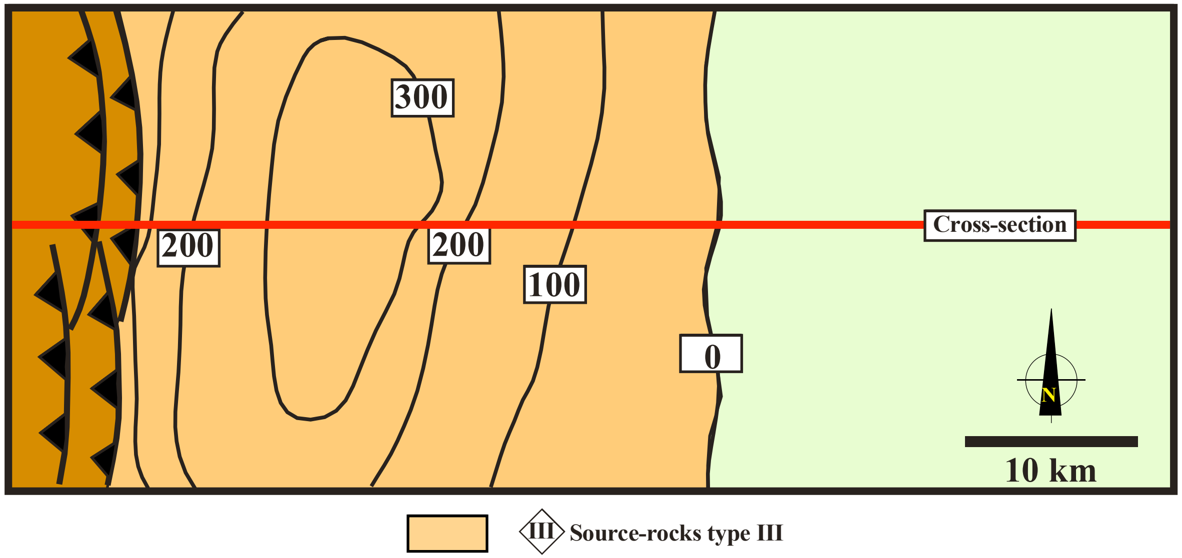
2) Mapping the potential source rock

Since explorationists are able to predict the most likely source-rocks, they must be able to map them have to cover. This mapping must be made not only horizontally but also vertically to evaluate the charging of th system.

The charging of a petroleum system was defined as the amount of hydrocarbons available for trapping, that is to say, the volume of hydrocarbons generated minus the volume hydrocarbon during migration (D. Sluijk 1984).

In the case of the sedimentary basin represented by the geological section illustrated in the previous figure, the mapping of the source-rocks might look like the map shown below.

Mapping of the Source-Rocks



Isopach map of source-rocks shown in previous figure. The source-rocks are present in the foredeep basin. However, they thin toward the craton and ending by onlapping.

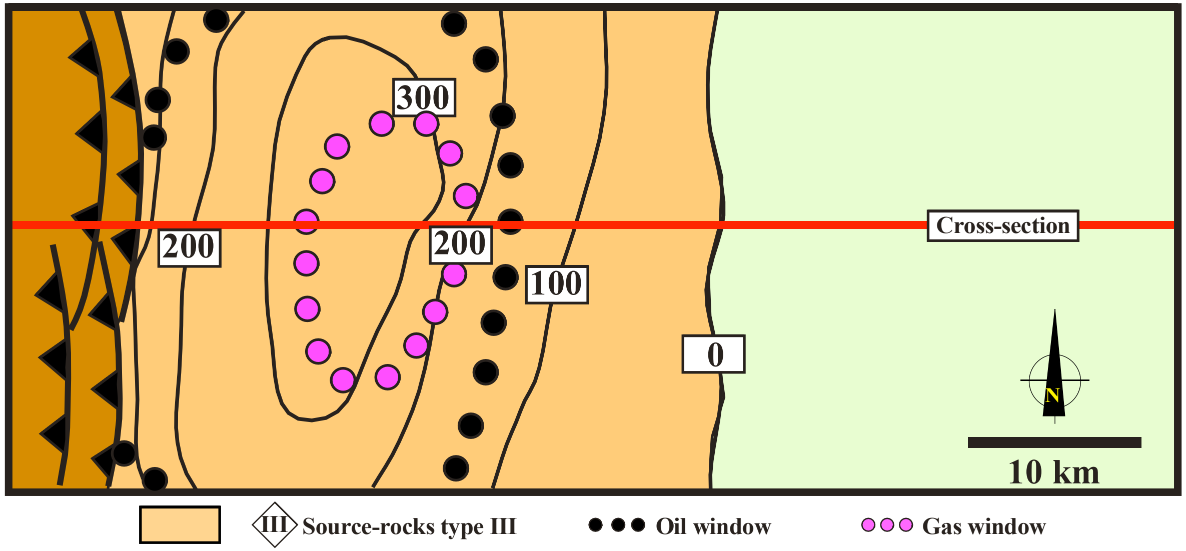
The volume of hydrocarbons (regional charge) depends on the richness of the source-rocks and the volume of source-rocks capable of generating hydrocarbons. Consequently, we need to map the areas of maturation, that is to say, to map the oil and the gas windows.

Petroleum System

3) Mapping of maturation zones

The mapping of the maturation zones, where potential source-rocks generates hydrocarbons depends on the depth of the source-rocks, age and heat flow. In the chosen example, this mapping would be approximately that shown below.

Mapping of the Maturation Zones



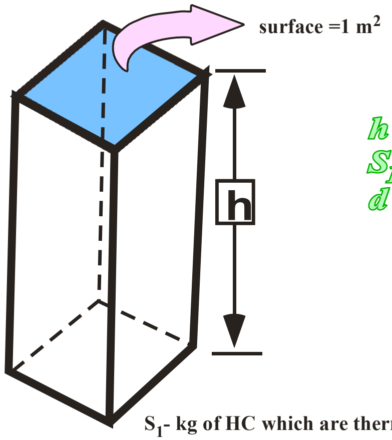
Mapping of the maturation zones superimposed on the isopach of the source-rocks.

An approximate value of the amount of hydrocarbons generated in a petroleum system can be achieved by knowing :

(a) The volume of mature source rocks mother ;
(b) The density of the source-rocks ;
(c) The potential parent rocks and
(d) The rate of conversion.

The generating potential of a source-rock or SPI potential is defined as the maximum amount of oil (metric tons) that can be generated by a column of rock of 1 m^2 of surface (see next).

Petroleum System



SPI
(Generating Potential)

h = thickness o the source-rock in meters ;
S_1+S_2 = average generating potential in kHC/m ;
d = density of the source-rock in tm/m^3

$$SPI = \frac{h(S_1+S_2).d}{1000}$$

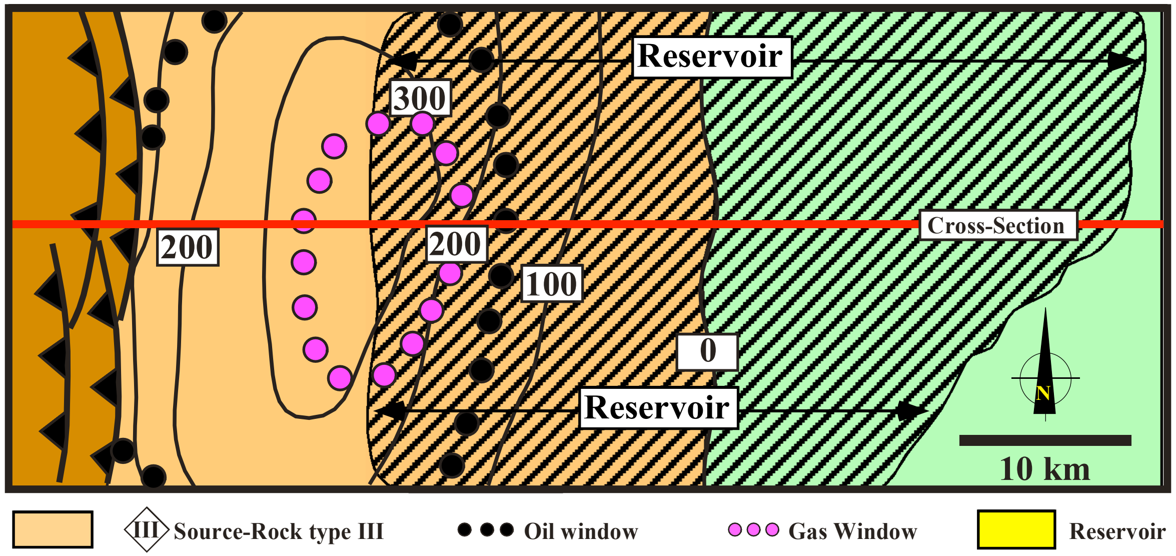
S_1- kg of HC which are thermically thermiquement distilled from 1 t of source-rock.
S_2- kg of HC, which are generated by pyrolithic degradation of kerogen from 1 t of the source-rock.

Formula for calculating the generating potential knowing the thickness, thermal potential (S_1) and pyrolithic potential (S_2) of a source-rock.

4) Mapping of the reservoir-reservoir

Once the exploratinist puts in evidence the more likely reservoir-rocks (closed), it must be mapped horizontally and vertically. In our example, the horizontal mapping would look like as shown below.

Mapping of the Reservoir-Rock



In this figure, the lateral extent of the potential reservoir-rock is superimposed on the previous maps, i.e., to the extension of the source-rock and maturation zones (oil and gas window).

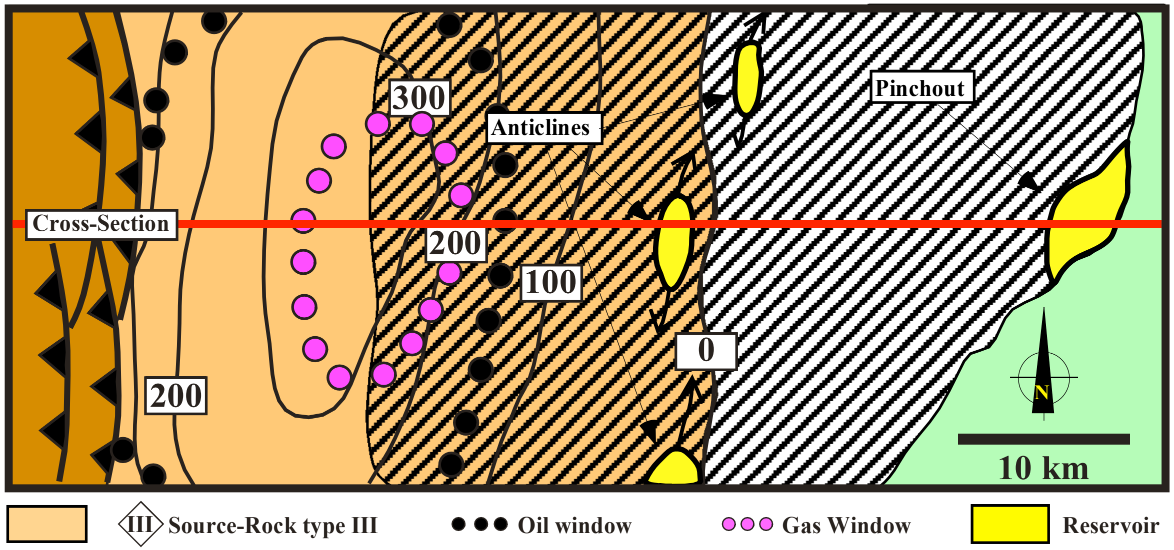
Petroleum System

5) Structural map of the reservoir - rock

Once the explorationist identified and mapped the extension the potential reservoir -rock (covered by a sealing interval), it must:

- **Make a structural map of the top of reservoir-rock (see below.) to highlight the most likely structural traps capable of concentrating the hydrocarbons generated by the source-rocks;**
- **Determine the age of the traps (they must predate the migration of hydrocarbons);**
- **Map the migrations-paths flyways (see below)**

Structural Map of the Reservoir-Rock



The structural map of the reservoir-rock has highlighted four potential traps. Of these potential traps, three are structural, that is to say, with a clean closure and one morphological associated with the onlapping of the reservoir interval against the infrastructure.

6) Mapping of migration routes

The hydrocarbons migrate laterally along the reservoirs to the traps, where they will create economic potential accumulations. A schematic map of the hydrocarbon migration paths might look like the one illustrate next. It is important to identify the migration paths allowing the concentration of the hydrocarbons rather their dispersion after their expulsion from the source rocks.

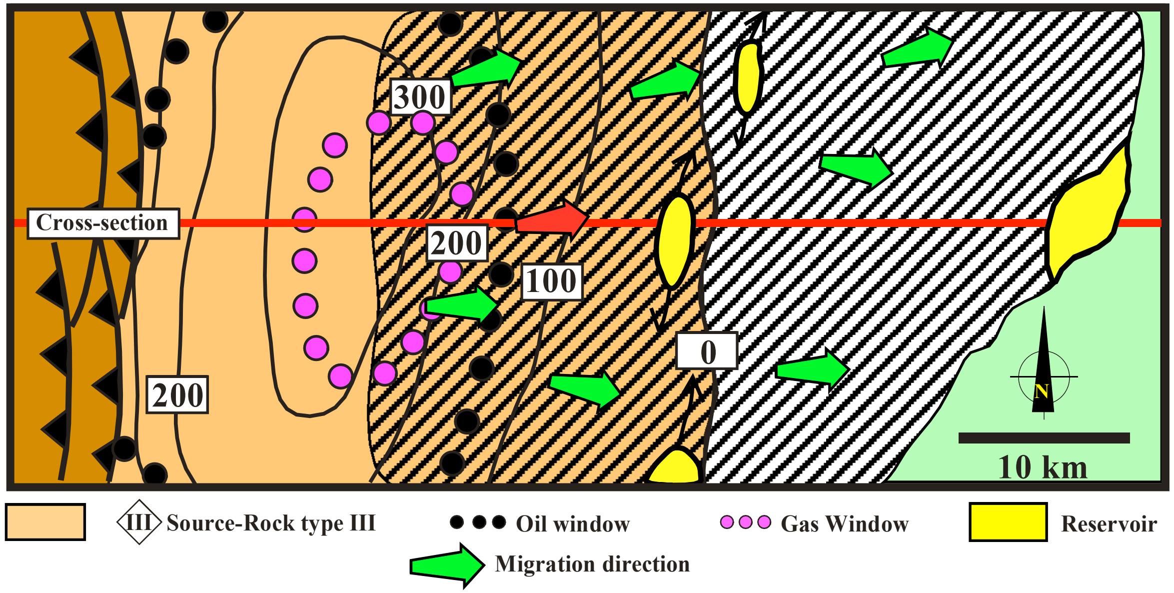
Petroleum System

The evaluation of the migration is a critical step to see if the drainage basin tends to concentrate or disperse the generated hydrocarbons. The migration is controlled by:

(i) The tectonic style and
(ii) The stratigraphy of the basin,

In part, it can be predicted if the explorationist knows the globall geological setting of the basin. Once again, in the study of petroleum systems: The understanding of the evolution of sedimentary basins is essential.

Direction of Migration



The most likely directions of the horizontal hydrocarbon migration are superimposed on the earlier maps. They show that they are quite favorable to the accumulation of hydrocarbons in the potential traps.

Depending on the type of migration the petroleum systems can be classified into two major groups (G. Demaison and Huizinga, 1991):

a) Petroleum systems lateral migration and

b) Petroleum Systems vertical migration.

Petroleum System

A petroleum system in lateral migration requires continuous regional seal and reservoir-rocks with significant lateral extension and a low degree of deformation. This type of migration is much more common in the basin of the class A (Rift-type basins, cratonic basins and divergent margins) than in the basins of the class B. The se developed, generally, in a compressive tectonic setting. Therefore, it is normal that a lateral migration occurs mainly in basins with low impedance.

The impedance of a pool expresses the resistance that it opposes to the dispersion of hydrocarbons, which naturally tend to migrate to the surface. Thus, according to the style of trapping petroleum systems can be classified into:

(i) Systems with high impedance and
(ii) Systems with low impedance.

- The formers are generally associated with compressive tectonic regimes, while those with low impedance are more frequent in extensive tectonic regimes. extensive tectonic regimes.

- A petroleum system with vertical migration is associated with significant deformation of the basin is in a compressive tectonic regime (Falcon Basin, Los Angeles Basin, etc.) or in an extensional tectonic regime (Campeche- Reforma basin, Rift-type basin of the North Sea, offshore Nigeria, etc.).

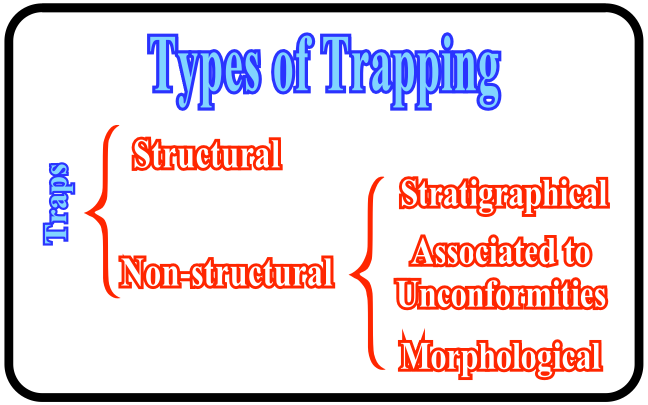
- What is important is that the deformtion of the sediments, whether by shortening or lengthening produces fractures along which oil may migrate.

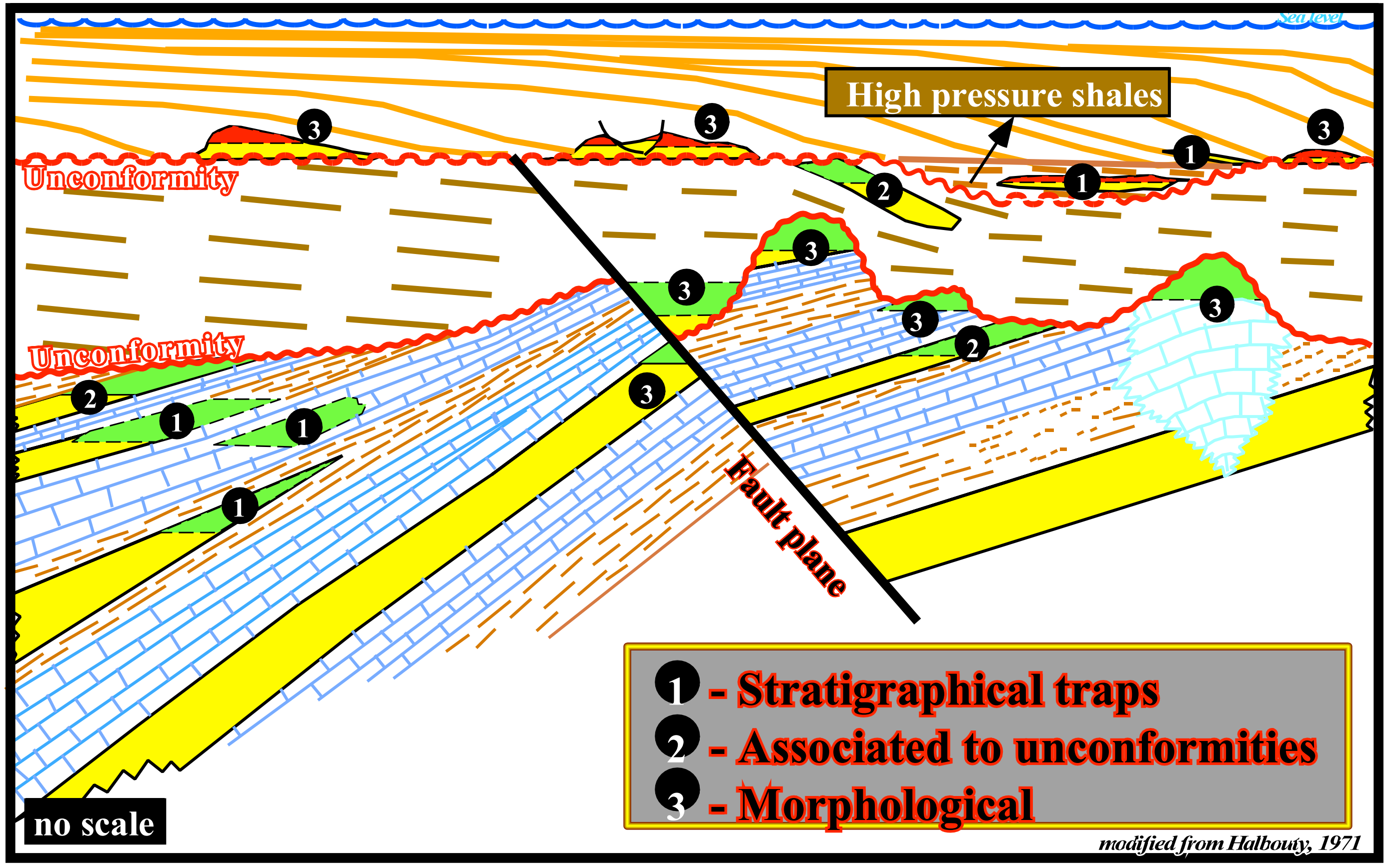
- As reported by several authors, a thick and continuous coverage is essential in a petroleum system with horizontal migration.

- In petroleum systems with vertical migration the sealing intervals are also needed to transport the hydrocarbons to faults or fractures so they can migrate vertically after.

Types of Trapping

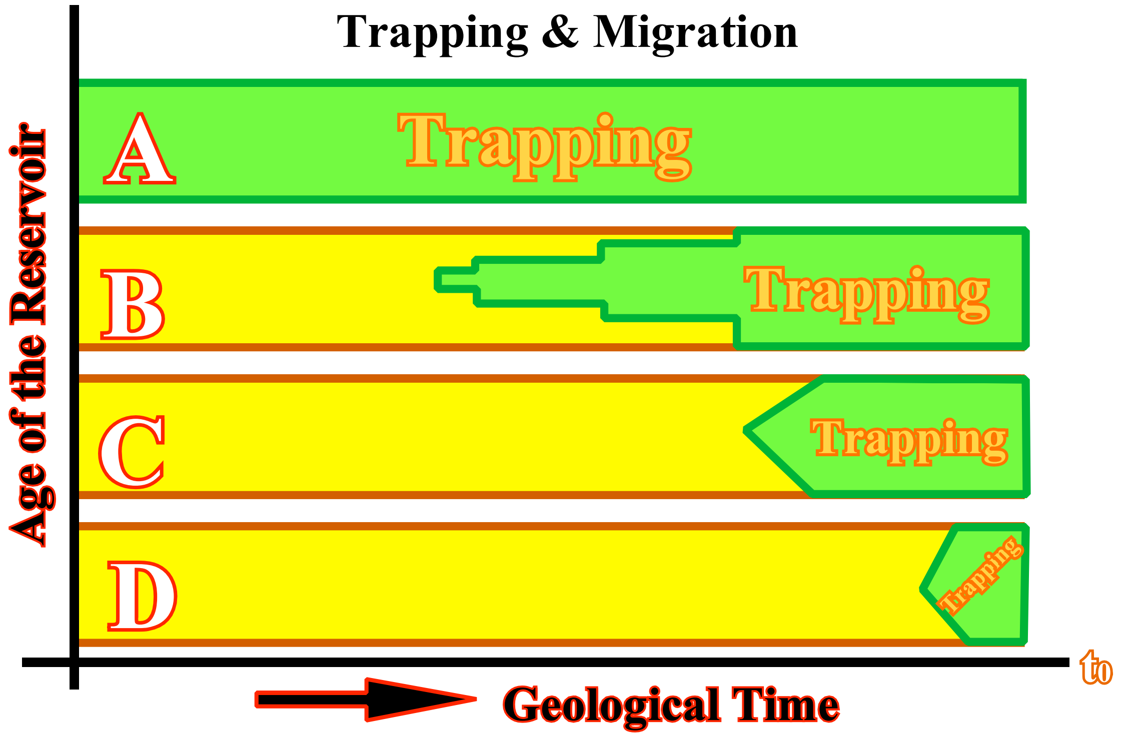
Non-Structural Traps





In Argentina, traps characterized by an upward concave geometry of reservoir-seal couplets and with a proper closure, i.e., with a four way dips, are practically absent or just locally present (in association with the reactivation of the fracture zones). The preponderant trapping mechanism is morphological by juxtaposition. Subsequently, a good knowledge of the locations of the potential reservoir and sealing-rocks (vertical and lateral) is required. The antiform structures developed above the buried hills of the substratum, by differential compaction, are not structural traps. The reservoir-rocks were lengthened by normal faults, as suggested by the time contour maps, and so, the maps of the top of the reservoirs do not fit with the maps of the top of the sealing rocks, i.e., the trapping mechanism is morphological by juxtaposition and not structural, since there is not a four way dips closure.

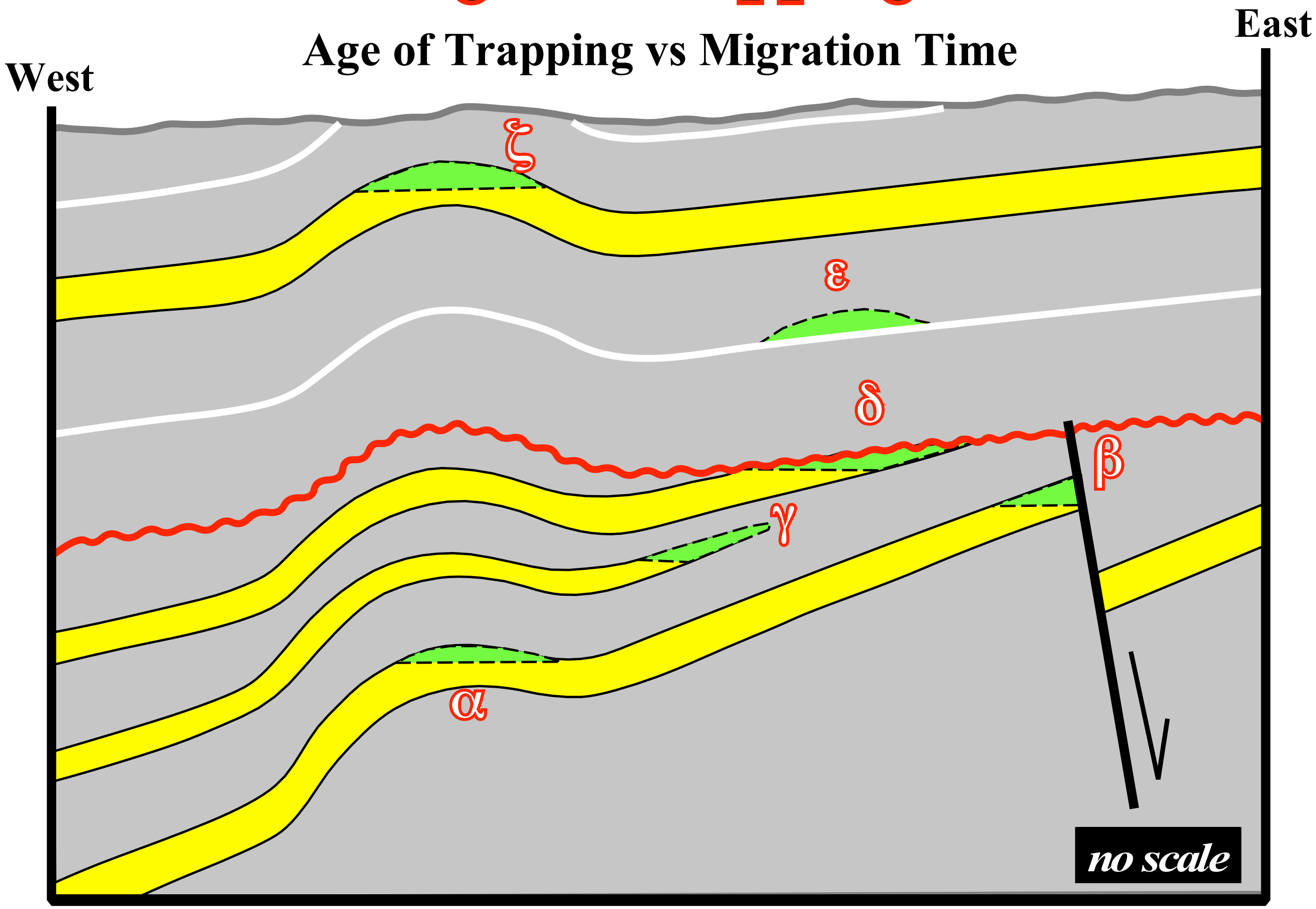
Age of Trapping



A - Non-structural (stratigraphical) and morphological traps.
B - Structural traps induced by several tectonic events or morphological by juxtaposition.
C - Structural traps associated with a single tectonic event.
D - Structural or morphological by juxtaposition traps associated with a late tectonic event.

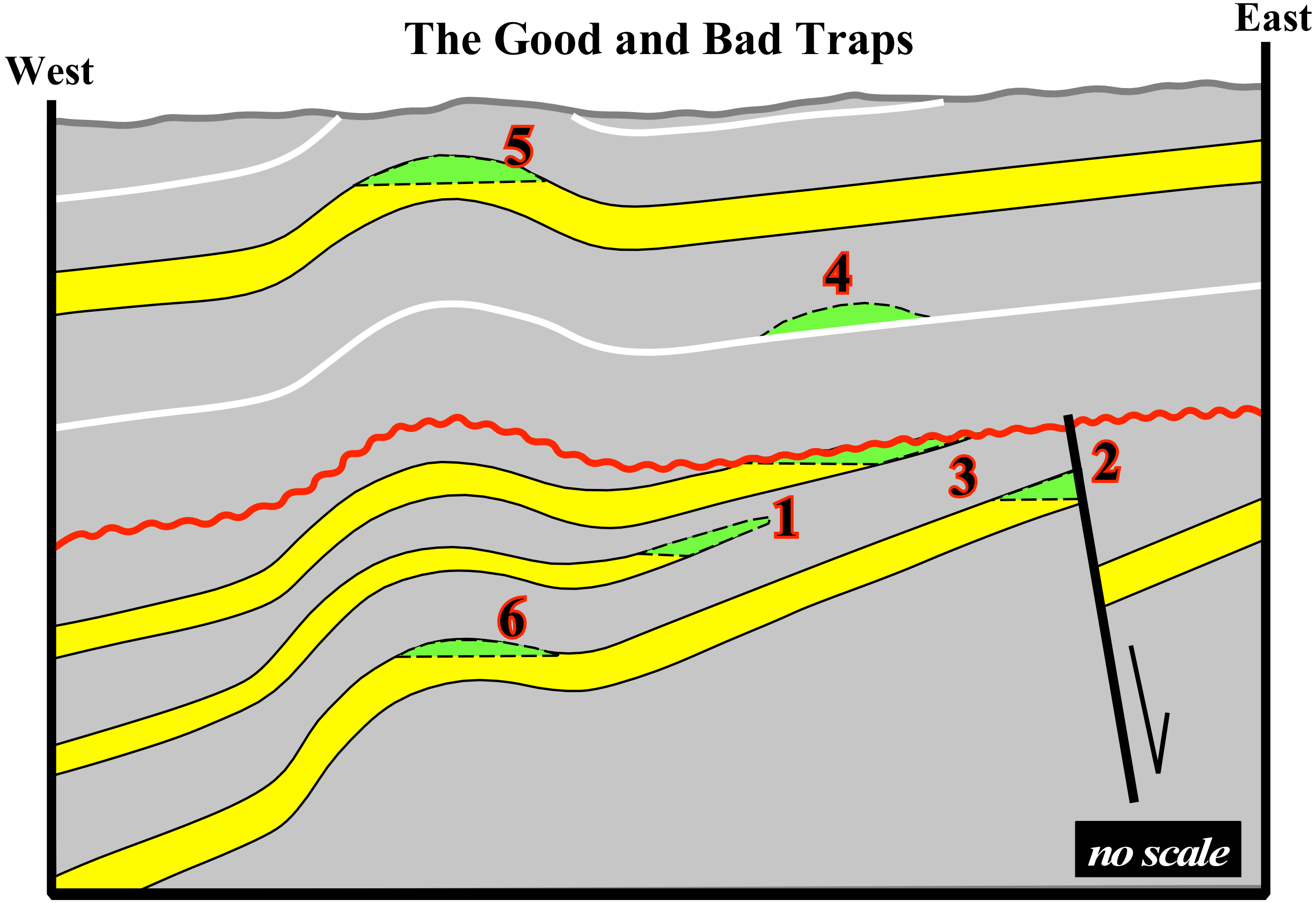
The results of the wells and particularly the discovery are enough to prove the presence of a generating petroleum subsystem in the several basins. So, the age of the trapping in relation to the migration time of the hydrocarbon is a crucial hydrocarbon parameter for a successful exploration. Luckily, the preponderant traps are non-structural: (i) stratigraphic (contemporaneous of the deposition) and (ii) morphological by juxtaposition induced by rifting faults. That means that the traps predating the migration of the generated hydrocarbons. The potential structural traps created by reactivation of old fracture zones are probably posterior to the main migration phase.

Age of Trapping



This example illustrates the importance of the age of trapping in the hydrocarbon exploration of Argentina basins. Indeed, the more likely generating petroleum subsystem, in certain basins, is located below a major unconformity (break-up unconformity), i.e., it is within the rift-type basins. The potential reservoir-rocks are located in the rift-type basins and above the break-up unconformity (Atlantic margin). So, assuming that the organic matter of source-rocks reached maturation during the deposition of the basal sediments of the margin, it is evident that some of the traps proposed in this plate are not good since some postdate the migration time. Before go to the next pages, please try to understand the trapping mechanism of each prospect and determine which are those that must be tested (drilled) or at least proposed to the Exploration Management.

Age of Trapping



Using the previous geological hypotheses (previous plate), which are more or less those prevailing at least in few Argentina Basins, one can say that the traps n°1 (stratigraphic), n° 2 (morphological by juxtaposition) and n°3 (associated with the break-up unconformity) are those with highest chance of accumulate economical hydrocarbons, since they predate the hydrocarbon migration. However, the traps n°2 and n°3 exist only if a lateral, and vertical, sealing-rock is present. In fact, ofen, the exploration game is the recognition and mapping of sealing-rocks, which are as important as the recognition and mapping of the reservoir-rock. Only when a potential reservoir is lateral and vertically sealed, hydrocarbons can be trapped (morphological trap by juxtaposition). In a practically manner, explorationists are obliged to map the top of the reservoir and sealing rocks. The other traps (n° 4, 5 and 6) postdate the migration of the hydrocarbons.

Trapping

Conventionally, when talking about trapping (structural or not) one refers to the trapping of a specific reservoi-rock. It is possible that multiple reservoirs form multiple traps. In thenmajority of the cases, the geological and petroleum standpoint, talking of a trap without specify the reservoir-rock does not make sense. This is, especially, true when an explorationitst shows on a map a huge antiform structure at the level of angular unconformity and thereafter, says the potential reservoir is underlying the unconformity. Every time an explorationist propose a stratigraphic trap at some level, the only map that is really significant is the structural map of this level, whether in isochronous or isohypses. We must not forget that there is no trap if there is no sealing. The mapping of the sealing rock (lateral and vertical) is one of the essential geological data for the definition of a trap.

Ultimately, in the case of stratigraphic traps, the map of the seal is more important than the map of the reservoir-rock. We emphasize, as did Downay (1980) long time ago, that a trap "against fault" is a misnomer. A fault, which is a mental construct of explorationists, do not trap. Which trap most often:

(i) Are the sediment located on the other side of the fault and which are juxtaposed to the potential reservoir-rockpotential ;

(ii) The sediments of the gouge zone.

For this, it is necessary that the capillary displacement pressure of the sediments juxtaposed to the reservoir-rock is higher than that of the reservoir-rock. Before moving to the next petroleum parameter, we will summarize below some basic principles on the trapping of hydrocarbons, which most often are ignored , particularly, by junior exporationists.

A) Geological Conditions

G. Rittenhouse (1972), admitted that the trapping of hydrocarbons in economic quantities, requires two simultaneous geological conditions:

(i) A reservoir

Generally, in a reservoir, there is an isolated portion and a low potential part. An isolated sandy body completely filled with oil is an exception to this sub-criterion.

(ii) A barrier (or sealing)

The sealing-rock must have an inlet pressure sufficiently high to retain oil. It is the minimum pressure required to oblige a trickle of oil or gas in a water-oil system through the wider pores and tubules of a reservoir .

Trapping

B) Migration

The migration of hydrocarbons, whether primary (expulsion of hydrocarbons from kerogen and source-rock) or secondary (hydrocarbon transfer to areas of lower pressure and temperature) follows the direction of decreasing pressure gradients. The hydrocarbons preferentially accumulate in areas of lower potential, i.e., in fractured zones and reservoir-rocks.

Depending on the predominance of the main geological isolation factor within the reservoir-rock or sector of lower potential, we can consider three principal categories of traps: (1) Structural ; (2) Non-Structural and (3) Hydrodynamics. Structural traps are, in all respects, a very special and different category from the other two. The closure, that is gto say, the barrier that forces the flow of hydrocarbons to accumulate upstream is very different from the closure of stratigraphic or hydrodynamic traps. This difference is marked not only at geometric point of view, but also from a dynamic point of view:

- At the geometrical point of view, the closure of structural traps comprises a concave chronostratigraphical surface downward the sealing layer, which characterizes all the traps associated with anticlines and antiforms.

(i) Obvious, this definition it is not applied at the traps associated of non-synchronous curvilineous surfaces, such as sandprone fans.

- These sandprone fans form, usually, sedimentary anomalies very recognizable. As examples, in the cratonic basin of the North Sea, on can mention the fans of Frigg and Balder.

(ii) Similarly, this definition does not apply to reef structures, such as those of the Upper Oligocene - Lower Miocene Superior in Indonesia / Malaysia, which are readily visible on seismic lines.

- The trapping associated with these sedimentary anomalies correspond to a particular type of non-structural traps called geomorphological traps.

- At the dynamic point of view, the difference between the closure of structural traps and that of others traps is even more pronounced. In non-structural traps, the barrier impeding the migration of hydrocarbons is, in most cases, the passage of a porous and permeable facies to finer grained sediment having a pore pressure, or entrance pressure, greater than the pressure exerted by the external fluid.

(i) In the case where the capillary pressure is sufficient to force the interface water-hydrocarbons through the pores of the sediments upstream, these sediments are no longer a barrier to the migration of hydrocarbons (the capillary pressure is the difference between the oil pressure and the pressure of the water).

Trapping

- The magnitude of the capillary pressure at which the hydrocarbon-water interface enter in the barrier is called entrance pressure or displacement pressure of the barrier.

(ii) In structural traps, the hydrocarbon flow is perpendicular to the sedimentary layers, while in other traps, the flow is parallel.

(iii) In faulted traps, that is to say, in the traps where there is a directly or indirectly participation of a fault, the trapping is fundamentally different of structural traps: The flow of hydrocarbons is not perpendicular to the sedimentary layers.

Structural traps, by their geometry, are very easy to identify and their closures are much more efficient:

- If the first layer above the reservoir-rock does not have a migrating displacement pressure high enough to trap hydrocarbons, there is always, in this type of trap, the possibility that higher stratigraphic levels have a displacement pressure appropriated can make a trapping.

- In some cases, we can differentiate the main sealing interval and induced sealing intervals. High pressure levels may have an indirect effect on the underlying sealing formations. These will act as induced sealings since they are surmounted by a layer with high pressure that works as the main sealing interval or cover.

The non-structural traps are harder to recognize:

- They are often very subtle and their detection from seismic lines is usually difficult.

- The closure is substantially formed by the displacement pressure of the levels stratigraphic, or fractures extending the reservoir-rock. Just a single more detrital bed having with a lower displacement pressure is sufficient to allow oil or gas migration.

- Sealings, under certain pressures and temperatures, are effective in some fluids and not for others. The result is a delicate and complex set of inputs and outputs of hydrocarbons : a trap is filled, when it is fed upstream, at a rate, more or less equal to the rate of losses downstream.

Trapping

C) Hydrodynamism

Traps located in the most parts of the basin more subsident are more likely to be filled than those in the stable or uplifted areas. E need to r^ka into account the aquifers andthe hydrodynamism hydrodynamics. They play a very important role in the effectiveness of the closure. Their effect is particularly important in the closures of the non-structural traps because the hydrodynamic gradient is parallel to the layers or to the faults, in other words:

“Parallel to the directions of preferential oil leaking”

In the evaluation of a trap, it is important, and often decisive, to know if there is hydrodynamics and if it is in the direction of the flow of oil or the opposite. The consequences are not the same:

(i) In the young sedimentary basins during subsidence, such as the cratonic basin of the North Sea or in the divergent margins of Atlantic type, most sedimentary series stillare in the process of compaction. The highest hydraulic potentials are in the central and deeper parts of teh basin: the hydrodynamic gradients are mainly centrifugal, that is tomsay in the upward direction.

ii) In the basins associated with the Meso-Cenozoic megasuture, such as in the episutural basins of the SE Asia or South America (back-arc basins) or in the périsuturaux basins (foreddeeps), which are globally in compression, structural deformations uplift and fold the sediments.

- These deformations are generally more pronounced along the old normal faults bordering the bedrock high and near the margins.

- The deeper parts of the basins with higher hydraulic potential, are often inverted as a result of shortening, and become structurally high areas. Thereby , hydrodynamic gradients are usually centripetal, That is to say, in downward direction.

In the evaluation of non-structural traps you should know that:

If the flow of the aquifer is in the same direction as the flow of hydrocarbons, it will decrease the effectiveness of the closure and eventually there is no trapping, as illustrated in the next figure.

Trapping

Not Favourable Hydrodynamic Flow

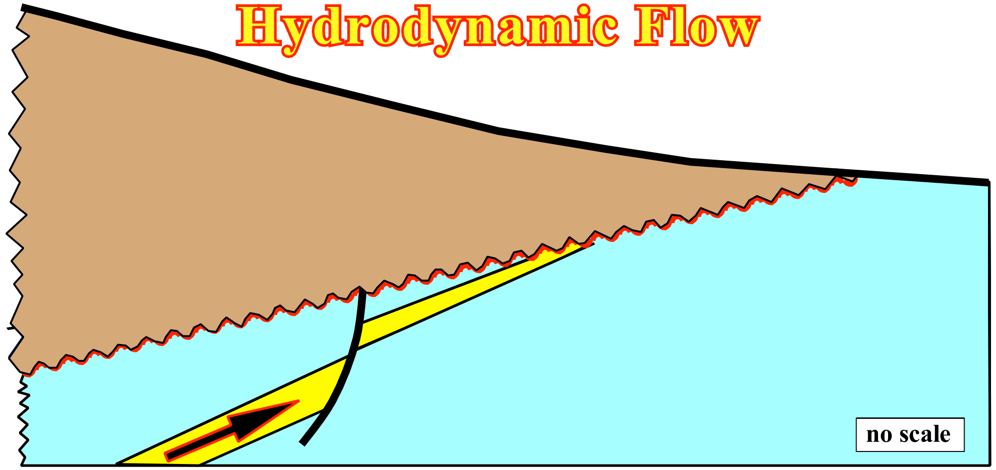


Diagram showing the harmful influence of a hydrodynamic flow (direction of the arrow) in the direction of hydrocarbon migration. There is no trapping either in wedges or in fault blocks of the reservoir-rock interval (yellow).

Under such conditions, to trap hydrocarbon we need to have very specific geological factors.

Migration is the direction of decreasing pressure gradients, the total amount of oil has likely migrated along the unconformity to areas of lower potential (a higher deposit or to the surface). However, if the reservoi-rock is protected by an overlying layer at very high pressure, this layer may be an effective seal and it is possible that hydrocarbon remain trapped in the reservoir-rock.

However, in order to get an hydrocarbon accumulation economically profitable, it is necessary :

a) An inactive hydrodynamism, and

b) A structural behavior of the reservoir-rock very low, close to horizontal.

If the flow of the aquifer is in opposite direction of the flow of the hydrocarbons (as illustrated in the next figure), it tends to oppose the migration of the hydrocarbons. This reinforces the closure of the trap, favoring significant impregnated columns.

Trapping

Favourable Hydrodynamic Flow

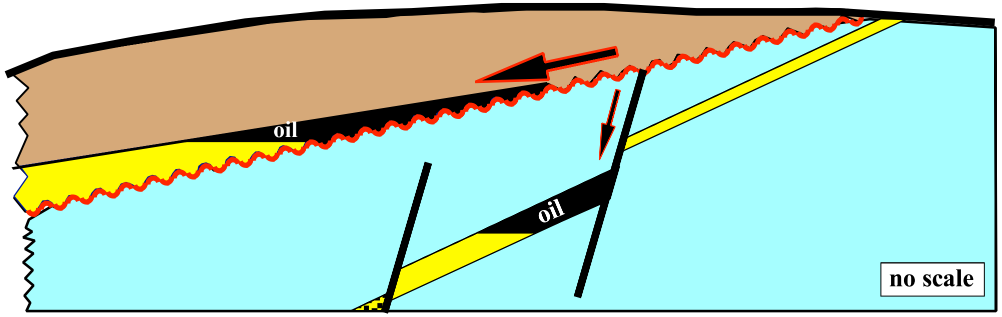


Diagram showing the positive influence of a hydrodynamic flow in opposite direction to the migration of hydrocarbons. There is often trapping in the pinchout of the upper reservoir-rock and the footwall of the first faulted block.

In this regard, the Gabian field, located in the department of Herault, which was operated by SNPLM before the Second World War, is a typical example. This old field, whose production would orbit 50-100b / d, had the particularity to have very quickly deflation. Despite this, every spring, after the winter rains, it started to produced. In fact, the rain, locally, increased a centripetal hydrodynamic flow of meteoric which prevented oil to disperse and migrate to the surface waters by trapping it. In structural traps, the influence of hydrodynamic gradients is much less pronounced. The flow of the aquifer, which is parallel to the bedding planes, has as main action the lateral displacement of the accumulation, as illustrated next.

Downward Hydrodynamic Flow

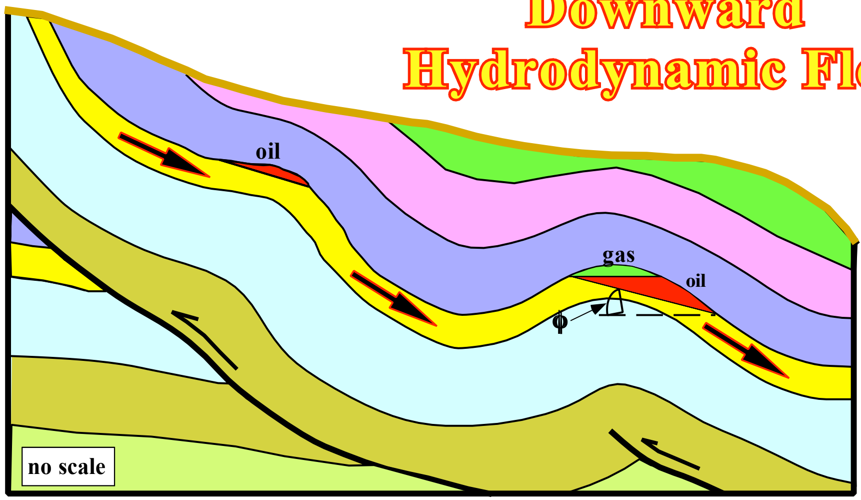


Illustration of the influence of a downslope hydrodynamic gradient in an anticlinal structural traps. The wall of hydrocarbon accumulation, i.e., the water plane is tilted in the direction of flow according to the law of Hubbert (see next).

Trapping

The wall of accumulation, i.e., the water-plane is inclined according to the Hubbert'rule (1953):

tgf = dh / dx X dw / (dw-dh)

In this formula:

f.................... represents the angle of water-oil with the horizontal plane.
dh / dx .... hydraulic gradient of the water table.
dw .... the density of water.
dh .... density hydrocarbons.

The tilting of the water-plane is, according to this equation, higher when hydrodynamic gradients are higher and the densities of the oil and water closer of 1.

When the hydrodynamic flow is very important the accumulation can be completely swept out of the trap. Under such conditions, it happens that in these traps the hydrocarbon column exceeds the theoretical closure, determined from the structural maps. It is therefore important to distinguish between:

(i) The theoretical closure, which is determined from geological, mainly seismic data and field.
(ii)The impregnated closure or practical closure, which is given by the height actually impregnated in the volume of the trap.

In structural traps and mono-layers accumulations (just reservoir-rock level), the impregnated closure can:

(a) Be equal to the theoretical closing (in this case, we say that the field has a load factor of 1).
(b) Less than the theoretical closure (in this case, the load factor is less than 1).

For accumulations mulri-layered deposits (several reservoir levels) we need to take into account:

(i) If there is a single water-plane (the height impregnated is then equal to the structural closure).
(ii) If there are several water-planes (the total height is greater than the largest structural closure).

In evaluating a structural trap, the explorationist must decide on these options and use more likely. In some cases, the prospect may not be of interest to economists. In others, it may be economically profitable.

Trapping

In the non-structural traps of some perisuturau or episuturaux basins, where the hydrodynamic gradients are often inward and in opposite direction of thr hydrocarbon migration, explorationists noted, with satisfaction, that the impregnated height of oil exceeded, sometimes for a lo , the theoretical closure determined from seismic or calculated by the formula Hobson (1954):

$$Zc = 2y\ (rt / rp) / g\ (rw - rh)$$

In this formula :

Zc is the height of the oil ;
y is the interfacial tension (interfacial tension, is work per unit area required to expand the interface between two immiscible fluids, in this case the water and oil) ;
rt corresponds to the radius the tubules between the pores ;
rp is the pore radius assumed equal to that of the oil drops ;
g is the gravitational force ;
rw is the water pressure and
rh is the oil pressure.

Such a finding can be illustrated by the famous example of the field Paduca (see below). This field, which is located in the Delaware Basin (State of New Mexico, USA), oblige explorationists to recognize the importance of the hydrodynamic conditions in the exploration of non-structural traps. Indeed, most of these traps provide economically viable accumulations when the hydrodynamic conditions are favorable. Otherwise, the accumulation does rarely exceed a geological success.

1) Paduca Field

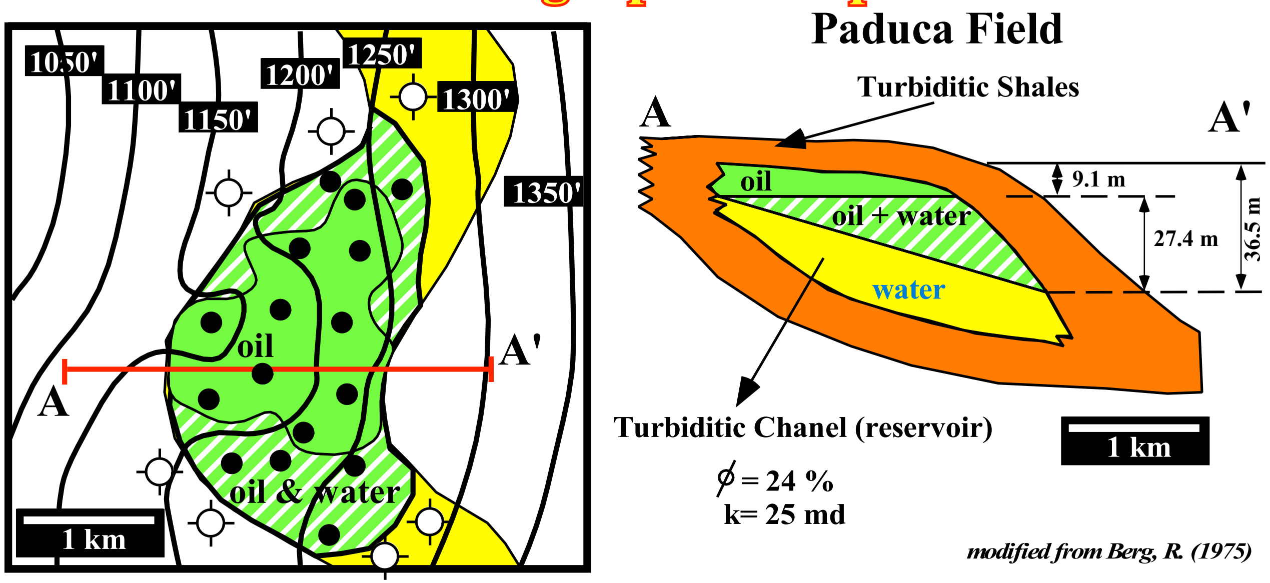
The field is associated with a thick turbidite series of Permian age, composed mainly by slope fans, which upper limit is slightly inclined to the east at 20 meters per kilometer. The reservoir-rock correspond to turbiditic sands that onlap a turbidite channel about 2.5 km wide that gently meanders along the North-South direction. This infilling is surrounded by the clay facies of aprons and overbank deposits of th slope fans that form the barrier for hydrocarbons. In the upper part of the field (in the East), the top of the impregnated reservoir-rock was found about 7 meters below the picked horizon (top of the slope-fans). The exploitation of the field has shown that the total impregnated height greatly exceeded the theoretical structural closure. This has led some explorationists to think that trapping was not under hydrostatic conditions.

Trapping

In 1965, R. McNeal showed that some turbiditic reservoir-rocks in the Delaware River Basin had a potentiometric gradient parallel to the sedimentary beds, and than a downslope hydrodynamic flow could easily explain the exceptionally impregnated height in Paduca field. From pressure data of the fields and potentiometric maps of the basin, he predicted a hydrodynamic gradient of about 4-6 meters per kilometer in some parts of the basin.

In 1975, R. Berg has shown that the theoretical values estimated for an hydrostatic and hydrodynamic traps were roughly the same as those observed in the field Paduca. This has reinforced the idea that trapping of the oil here was the result of several geological factors and the Paduca field can not be taken as a stratigraphic trap in the meaning of Levorsen L. (1936).

Stratigraphic Trap



The isopach map of the top of turbidite deposits, the mapping the channel, which forms the Paduca field, the section AA' and production results show that the total height of the accumulation exceeds, largelly, the structural closure.

As a conclusion, we can say that there is very similar results between oil columns calculated from the equation of capillary pressures of Hobson (1954): **Zc = 2y (rt / rp) / g (rw-rh)** and those observed in some non-structural traps shows that the capillary theory largely controls the migration and trapping of hydrocarbons:

(i) The capillary theory is an important tool for the exploration of such traps. It was very rarely falsified.
(ii) This theory can be used in the remnant exploration of mature basins at structural point of view, but still have an important non-structural petroleum potential.

Trapping

(iii) It is in these basins that much of the exploration effort has to be done, especially in those where the source-rocks have an important charge, because large reserves remain to be discovered.

(iv) The message of R. Berg (1975) on this subject is very significant:

> Millions of barrels of oil are probably present in simple non-structural traps, but they will be difficult to to find because there is no structural evidence of their existence. The knowledge of fluid properties, particularly capillary and hydrodynamic pressures, combined with interpretations of depositional environments, will be a significant aid in exploration.

It is likely that the rift-type and cratonic basins of the North Sea, the back-arc basins of SE Asia (especially Sumatra) and of South America (Maracaibo, Neuquen basins back etc.), Tertiary basin onshore USA (Louisiana, Alabama), etc., still have pleasant exploration surprises.

2) Milbur Field

The Milburfield is located in County Burlescon (Texas). It has become a classic to illustrate one of the oil exploration approaches, non-structural traps. The history of this discovery can be summarized as follows:

a) The first exploration well was drilled far downdip of the onlap of a mouth bar.

b) It crossed about 7.5 meters of a highly porous and highly permeable reservoir-rock.

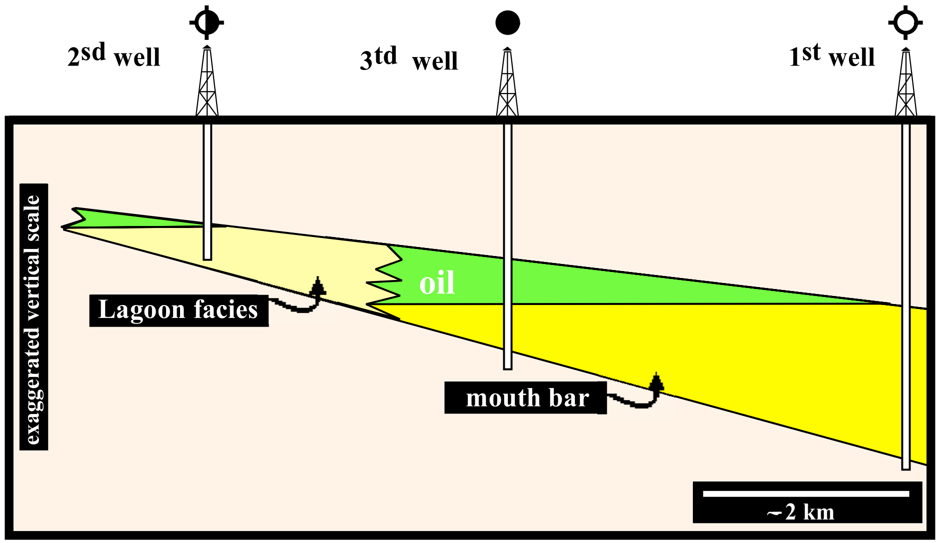
c) A second well was located approximately 6 km updip of the first one.

d) It met very fine lacustrine sands with low porosity and permeability. In test, the well produced water with traces of oil.

e) An oil accumulation was predicted downdip, in association with the onlap of the reservoir-rock.

f) The thickness and the petrophysical characteristics were such that the accumulation had no chance of being economical.

Trapping



Malibur Field (USA)

Schematic geological cross section of the Milbur field in onshore Texas. Note that most of the oil is trapped between the first and second wells, i.e., downdip of lagoon facies which works s a lateral seal.

g) From the knowledge of the porosity and permeability of reservoirs penetrated in the first two wells, explorationists have calculated the theoretical oil heoght from Formula Hobson.

h) Their calculations recommended a third well, that explorationist located between the previous wells.

i) The third well discovered of Milbur field (S. Chubert 1972).

D) Levorsen's experiments

Beyond the stratigraphic and structural trapping factors, the fluid movement and particularly, the speed and direction of water flow, i.e., the hydrodynamism of Levorsen (1939) (hydros = water, dynamikos = movement, strength) wre the third factor that controls trapping. Several geological events can be invoked to explain the hydrodynamism :

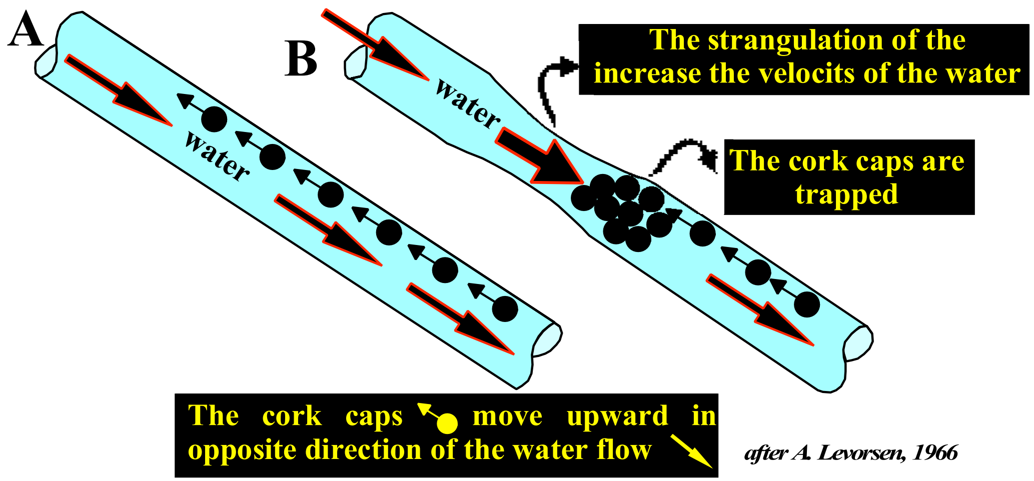
a) Different composition and density of fluids ;
b) A shortening of the sediment, inversions, orogens, erosion ;
c) Lengthening of the sediment with tilting ;
d) Volcanism, heating and cooling of the sediments ;
e) Diagenesis, etc, etc.

Trapping

Levorsen (1966) simulated in the laboratory an hydrodynamic trapping using a transparent glass tube and cork caps, as shown in figure below:

- In the tube A, the water movement is toward the bottom of the tube and the cork caps due to their buoyancy (Archimedes thrust) moves upwardly in opposite direction of the water flow. They are in hydrodynamic equilibrium.

1st Levorsen's experiment



In this experiment, the water flow is parallel to the walls of the glass tube, but in opposite direction buoyancy of the co. The constriction of the glass tube increases the velocity of the water and the corks are trapped. This experiment shows that hydrodynamism is an important trapping factor.

- B In the tube, a slight strangulation in the glass tube causes a restricted area, characterized by a more rapid water flow and sufficient to cancel buoyancy of the cork caps, producing their trapping.

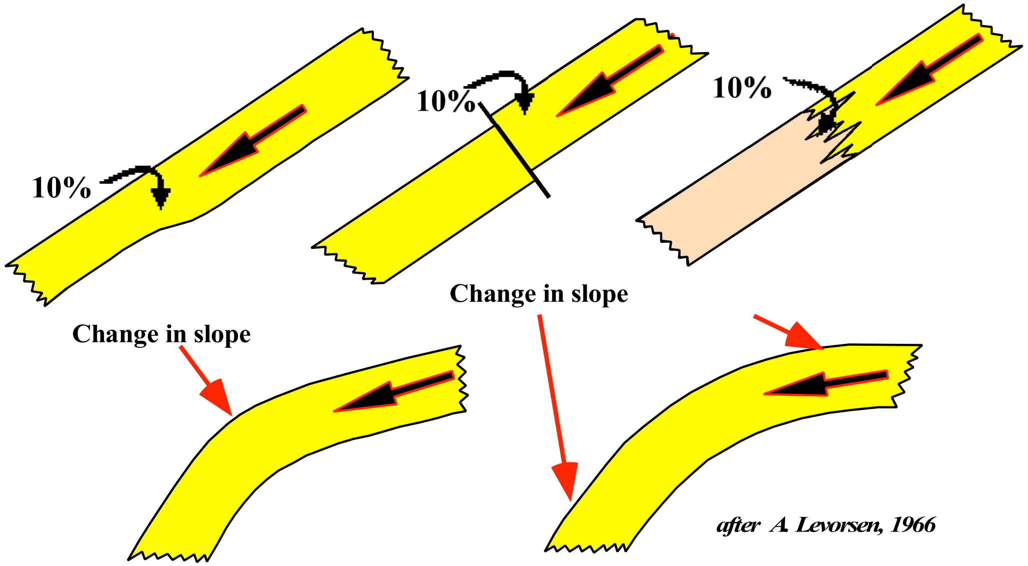
In nature everything seems to happen in the same way:

- The water moves along the reservoir rocks (the glass tubes of the experiment) and the bubbles or droplets of oil (cork caps) move to the areas with lower potential.

- Hydrocarbons can be concentrated and trapped by hydrodynamism below areas where the water flows down is big enough to overcome tand balance heir buoyancy.

Trapping

2sd Levorsen's experiment



Changes in the structural or stratigraphic behavior of a reservoir-rock may induce an increasing of the downward flow of the aquifer and reduce the buoyancy of oil droplets. This affects the balance of fluids and can cause the trapping of the hydrocarbons.

Apart from all other trapping mechanism, hydrodynamism provides very rarely significant accumulations. Several structural, stratigraphic and chemicals factors can alter the flow of the aquifer in the reservoir-rocks:

1- Density difference between the fluids;
2 - The proportions of the different fluids;
3- Changes in the porosity of the reservoir-rock ;
4- Changes in the thickness of the reservoir-rock ;
5- The pressure gradients which control the flow rate of the aquifer ;
6- Changes in slope of teh reservoir-rocs;
7- The presence of faults, etc.

Another Levorsen experiement, which is illustrated inext explains some accumulations associated with the reservoir-rocks in anticlinal structures, such as those in the Mahakam Delta (Handil, Bekapai, Tunu), Murphy Dome, Frannie (Rocky Mountains),

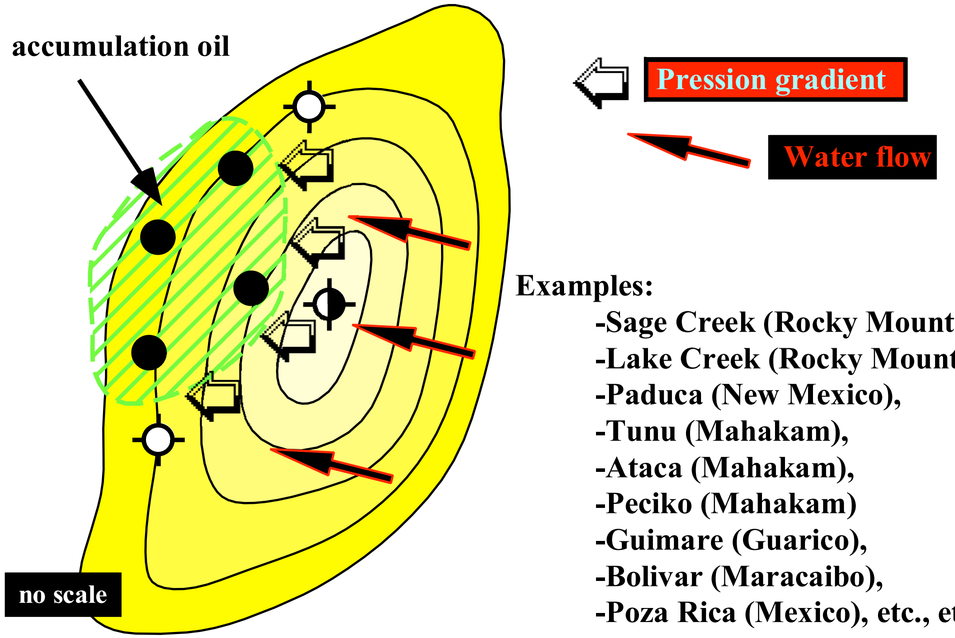
Trapping

Some accumulations associated with the flanks of antiforms induced by the rise of salt diapirs (Gulf of Mexico), which are often regarded as typical structural traps are indeed mainly due to lateral facies changes and / or hydrodynamic gradients descendants.

The theoretical example illustrated ibelow is that of an anticlinal structure with a very active hydrodynamics:

- **Changes in the dip in the left flank, that dip in the direction of hydrodynamic flow may be sufficient to create a favorable hydrodynamic gradient trapping of hydrocarbons, which tend to move to the top of the structure.**

Tapping by Hydrodynamism



Examples:
- **-Sage Creek (Rocky Mountains) ;**
- **-Lake Creek (Rocky Mountains) ;**
- **-Paduca (New Mexico),**
- **-Tunu (Mahakam),**
- **-Ataca (Mahakam),**
- **-Peciko (Mahakam)**
- **-Guimare (Guarico),**
- **-Bolivar (Maracaibo),**
- **-Poza Rica (Mexico), etc., etc..**

This diagram shows a geologic model where trapping is the result of the combined action of two factors, one is hydrodynamism, the other structural. This model easily explains the features of some well-known oil fields, some of which are shown as examples.

In each accumulation, we are often faced with trapping factors of different types: (i) Structural ; (ii) Stratigraphic and (iii) Hydrodynamic. The combination of these combine, in any proportion and at any scale, create traps against the dispersal and migration of hydrocarbons to the surface.

Trapping

So far we have tried to show in a very eclectic way that the trapping of hydrocarbons is, most often, the result of several factors . For several decades, this is the theme defended by a ceratin number number of explorationists. Apart from some very prolific structural alignments, economically profitable oil accumulations are almost always:

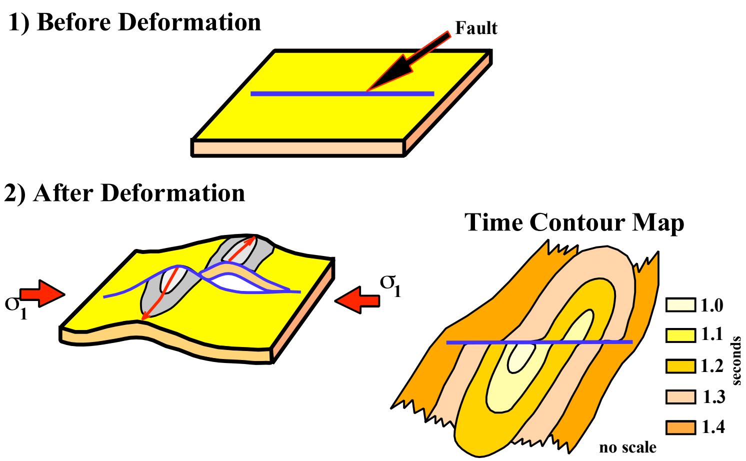
"the result of the simultaneous combination of several favorable geological factors: structural and lithological hydrodynamic"

It is not forbidden to say that as soon as one this factors (lithological, structural or hydrodynamic) is negative there is no trapping, or the amount of trapped oil is not large enough to be profitable. In the best case, there is a geological success, but most often there is no economic success. All external factor strengthening the closing of a trap plays a key role in hydrocarbon exploration, especially in the non-structural traps. For all these reasons we understand that it is very difficult to make a genetic classification of traps. Nevertheless, this classification remains necessary, at least for the exploreratìonists that could understand it. Below, we propose the classification of traps Halbouty (1966).

E) Tectonic Inversion & Hydrodynamism

Before ending this chapter we would like to insist that sediments are not necessarily isotropic and homogeneous: They are anisotropic and heterogeneous. So, under a regional compressional regime, the effective stresses can reactive old fracture zones individualizing different blocks within sediments are shortened independently. "Apparent" strike-slip faults are one of the reactivations which are very often misunderstanding. The following sketch what should be understood by an "apparent strike slip fault":

"Apparent" Strike Slip



The presence of a pre-existing fault zone or a weak zone can apparent displaced new formed structures. Indeed, in this particular example, both blocks of the pre-existent fault were deformed independently, creating two more or less parallel anticlines, but not to anticlines rejected, since the fault zone is pre- and not post-deformation. Such mechanism can explain several "s trike slip faults" in onshore Venezuela, as the Urica or Anaco fault.

Trapping

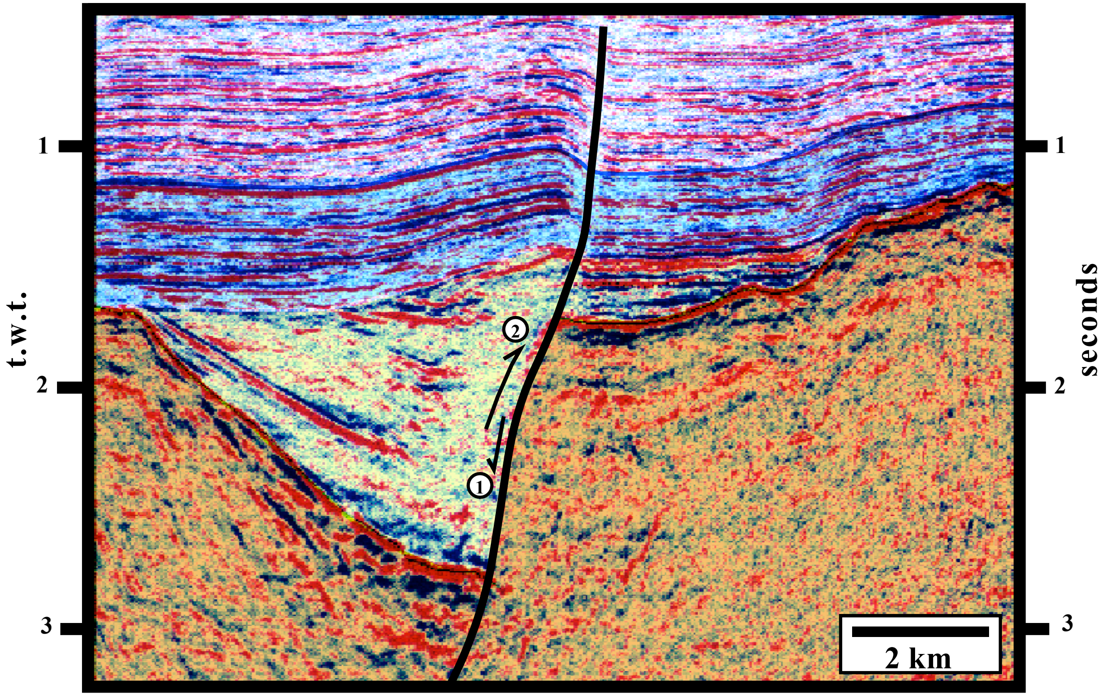
Similar results are obtained when a compressional tectonic regime follows an extensional regime:

a) During an extensional regime, with a σ_1 vertical, normal faults are developed parallel to σ_2.

b) Later on, during a compressional regime (σ_1 horizontal), the fault planes of pre-existing normal faults will be reactivated creating "inverted structures" such as the one illustrated below.

c) The reactivation of pre-existent faults, or weak surfaces, obeys to two main geological laws. Before analysing the laws controlling the reactivation, we will summarize the implications of the presence of a null point in a fault plane.

Tectonic Inversion



On this seismic line, a tectonic inversion created by the reactivation of pre-existing extensional structures is quite evident. The pre-existing normal fault of the half-graben rift-type basin, was later reactivated as reverse fault during a compressional tectonic regime. Taking into account that the tectonic inversion was not total, two geometries can be recognized along the fault plane: a normal geometry in the lower part and a reverse geometry in the upper part of the fault plane. These geometries are separated by a point where apparently there is no displacement - the null point.

Trapping

Null point

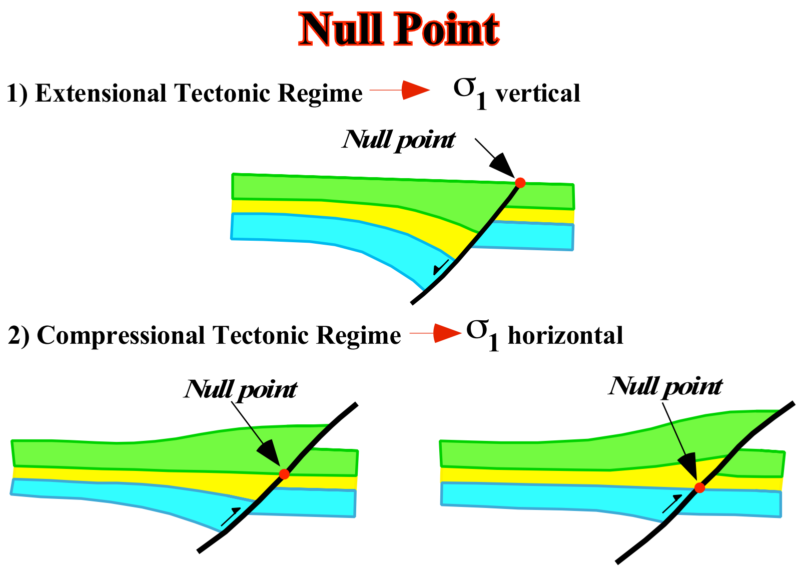
The marker that appears "unfaulted" on the fault plane is the Null point.

- In a normal fault, the null point is always located in the uppermost section of the fault plane.
- When a normal fault is reactivated in reverse, during the reactivation, i.e. during the reverse movement of the fault, the null point moves downward.
- The final fault is reverse fault (compressional tectonic regime).

However, as said previously:

1) Above the null point, the reverse fault thas a reverse geometry.
2) Below the null point, the reverse fault has a normal geometry.

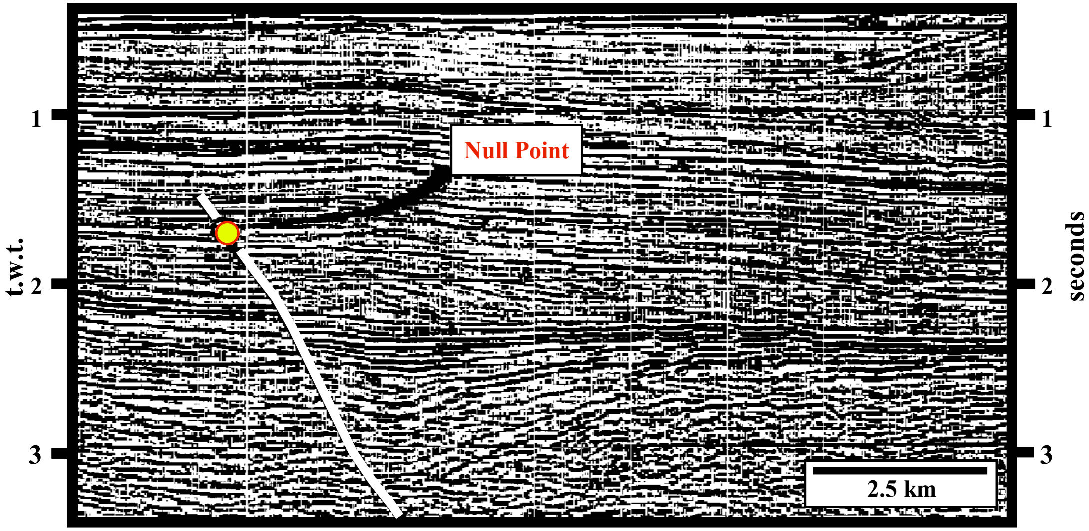
These geometries are clearly recognized on seismic lines, when a compressional tectonical regime was present in the area. Indeed, a compressional tectonic regime follows always an extensional regime : the sediments before being deformed must be deposited and deposition takes place during extensional tectonic regimes



Below the null point the geometry of the fault is that of a normal fault, while above, the geometry is that of a reverse fault. The position of the null point on the fault plane depends of the amplitude of the inversion. Higher is the null point smaller is the inversion. When the null point is on the bottom of the fault plane, the inversion was total, and so only the reverse geometry is recognized.

Trapping

Tectonic Inversion



On this North Sea line, the null point is located on the upper part of the fault plane : (i) It limits a normal geometry below it, where the sediments still seems lengthened, from a normal geometry, where the sediments are slightly folded ; (ii) The tilted fault blocks developed during an extensional tectonic regime, are sealed by transgressive sediments which underlying a progradational interval ; (iii) These intervals, which can be identified on the hangingwall and the footwall, allow stratigraphic correlations and the calculation of the fault displacement.

The reactivations on North Sea have been explained as a consequence of two mjor factors:

a) The Alpine's orogeny

During the Late Tertiary, the Alpine's orogeny effective stresses were transmitted northward along the basement's laminations reactivating the pre-existent normal faults.

b) Ridges push

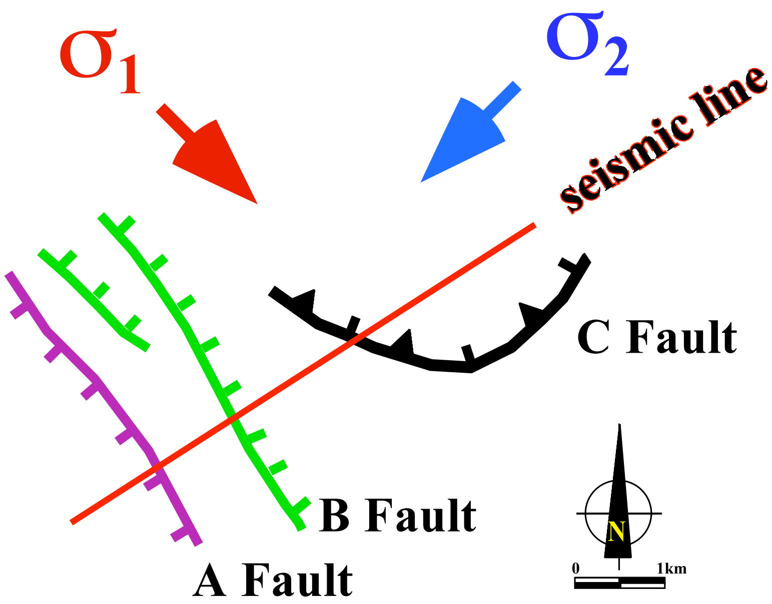
This hypothesis is corroborated by the analysis of focal mechanism of the earthquakes and certain deformation, which cannot be induced by conventional tectonic regimes. In fact, focal mechanisms in offshore Norway clearly indicates a reverse mechanism with a σ_1 striking N 110°.

Trapping

Angle between s1 and the strike of the pre-existent fault

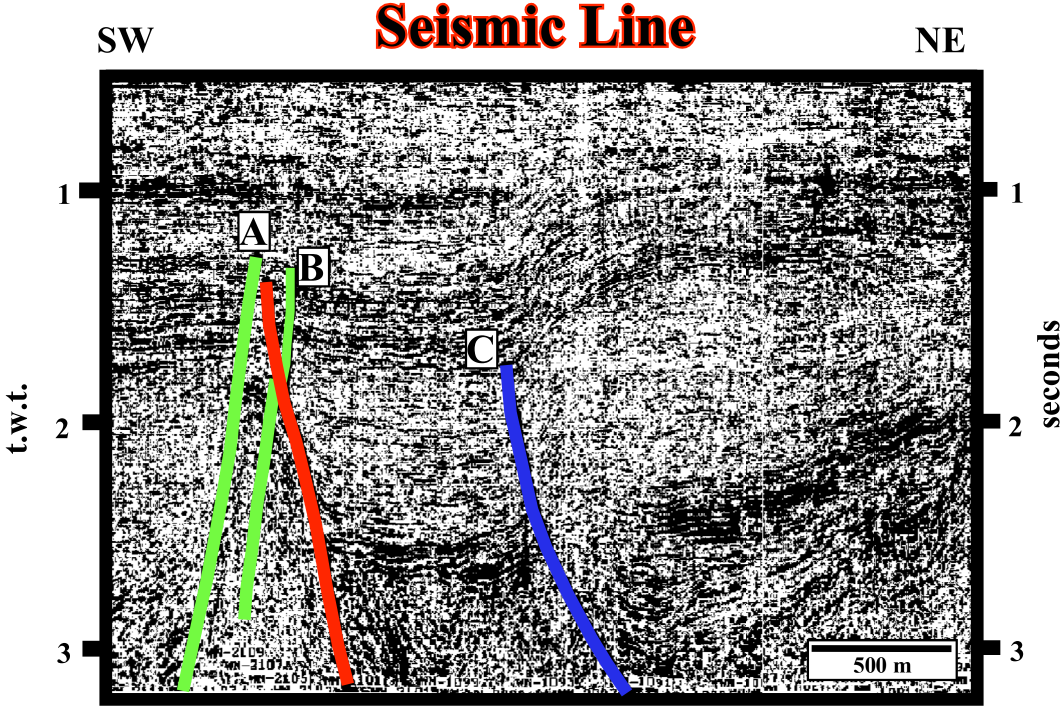
As said previously, the reactivation of normal faults by compressional tectonic regimes is function of the angle between the σ_1 of the compressional tectonic regime and the strike of the pre-existing faults :

Tectonic Sketch



On this tectonic sketch there are three faults belonging to quite different tectonic regimes. They have different direction, Subsequently, when the area will be affected by a new compressional tectonic regime, they will be reactivated in different ways as corroborated by the seismic line on the right.

Seismic Line



This seismic line corroborates the fact that only the fault C, which strikes roughly perpendicularly to the new σ_1, was reactivated as reverse fault creating a sharp tectonic inversion and probably a structural trap (four way dips).

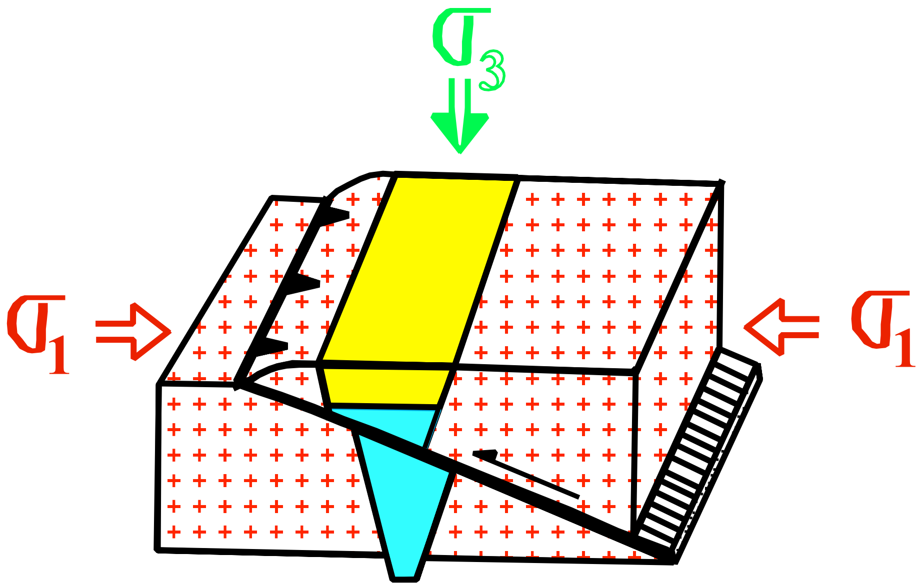
In the previous tectonic sketch, one can predict:
- The normal faults A and B, strike in a parallel direction to σ_1 of a younger compressional tectonic regime, are not reactivated.
- The fault C striking almost perpendicularly to σ_1 is reactivated as reverse fault.

Trapping

Angle between s1 and the dip of the pre-existent fault

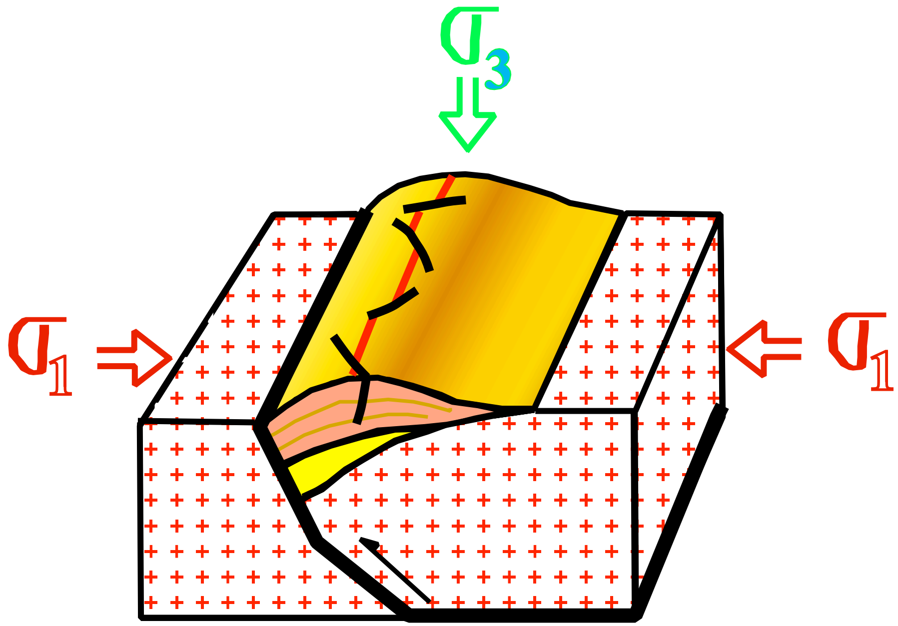
The reactivation of a normal fault by a compressional tectonic regime is, firstly, a function of the: angle between σ_1 and the dip of the fault : (1) Planar Faults and (2) Non-Planar Faults.

Planar Faults



The pre-existing grabens bounded by normal faults dipping 60° and striking perpendicularly to σ_1 were not favorable for reactivation. Subsequently a new reverse fault, perpendicularly to σ_1, was created.

Non Planar Faults



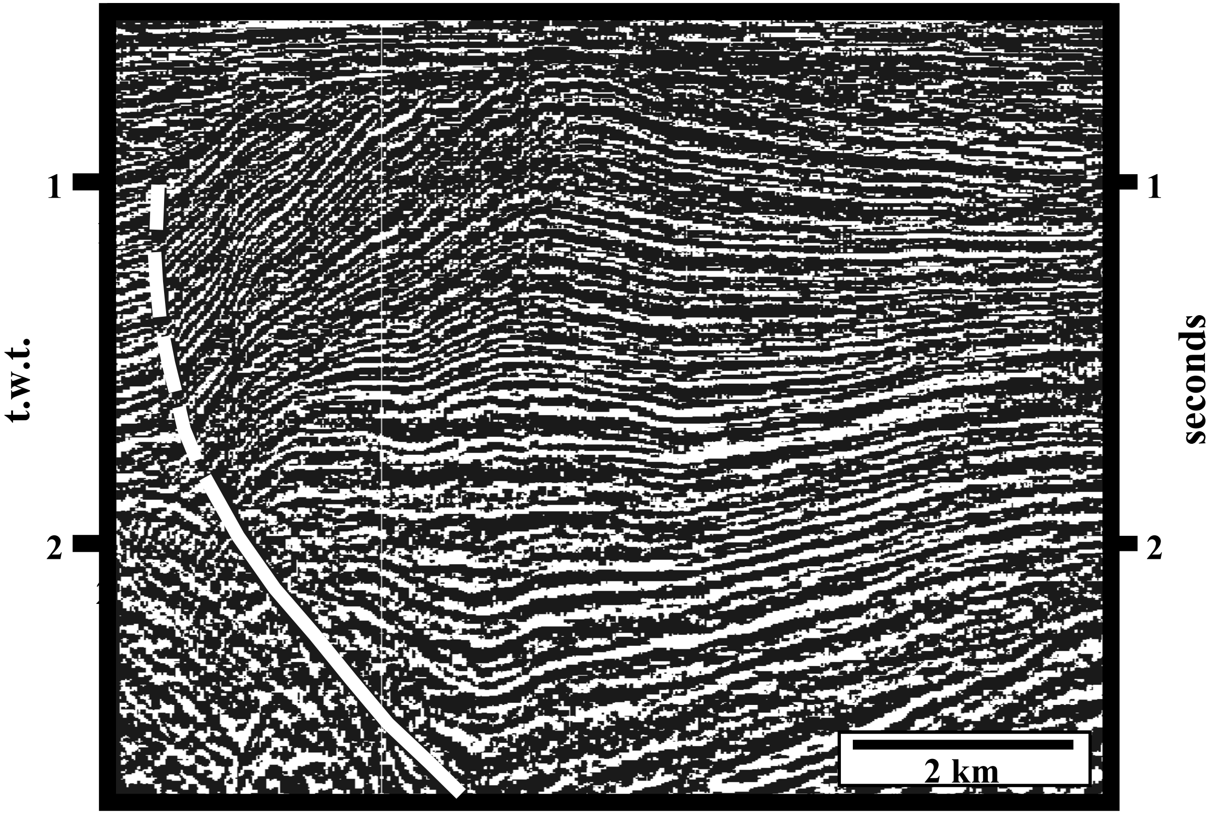
In non-planar normal faults, the deepest part, with a dip of 45° or less, is far from the optimum conditions for reactivation. Contrariwise, the shallow part having a high angle can not easily be reactivated and inversion, by buckling and folding, occurs above the fault plane. Consequently, as illustrated, two opposite geometries can be recognized. In the lower part a synforme geometry and in the upper part an antiforme geometry.

On seismic lines, the small strike-slip faults on the top of anticlines are often erroneously interpreted as normal faults associated with an younger extensional tectonic regime (what can happen). Their apparent normal geometry is easily refuted by the cartography. Their mapping shows (i) they are limited to the apexes of the anticlines, (ii) they arIn conclusion, they are not associated with a regional extensional tectonic regime, they length the anticline's axes, so they are associated with compressional regimes.

Trapping

As suggested in the previous block diagram, on the seismic line below a non-planar normal fault developed during an extensional tectonic regime later under a compressional regime. It was reactivated in the lower part of the fault plane, where the dip is around 45° or less, as a reverse fault, while the upper partof the fault plane inversion was by buckling and folding.

Non-Planar Faults



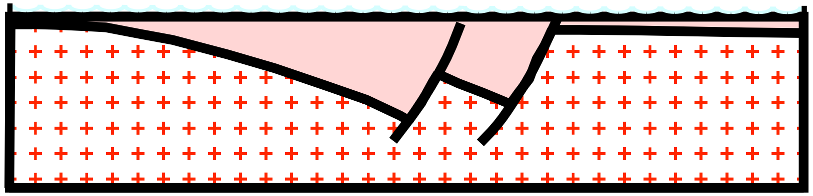
One can say the lower part of this non-planar faults was reactivated by inversion, i.e. the sediments were shortened by a reverse movement of the pre-existing normal faults, whereas as in the upper level, the sediments were shortened by folding. Consequently, in the upper sediments, i.e., those shortened by folding, it is normal to find small strike slip faults near the apexes of the anticlines. These strike slip faults allow the lengthening of the sediments along σ_2, as a counterpart of the shortening along σ_1.

The reactivation of pre-existing normal faults is extremely frequent in the sedimentary basins associated with the formation of megasutures. Back-arc basins, associated with the Meso-Cenozoic megasuture, are rich in inverted structures which are excellent hydrocarbon traps. These traps are structural and with favorable hydrodynamic factor as illustrated next.

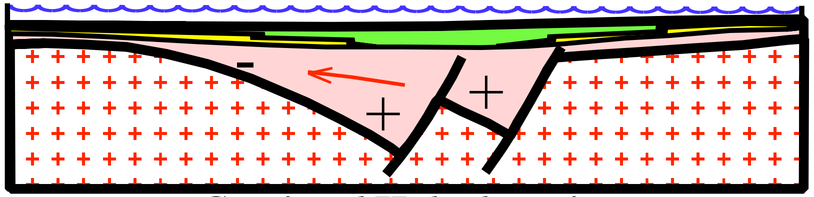
Trapping

Favorable Hydrodynamic Factor

Extension & Infilling

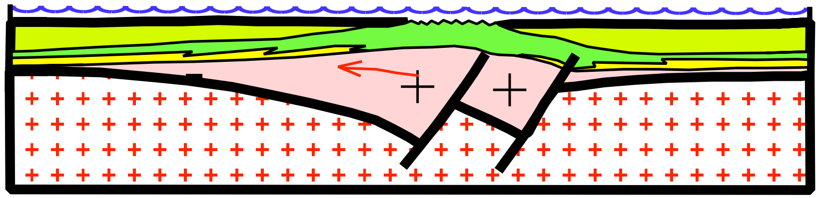


Transgression



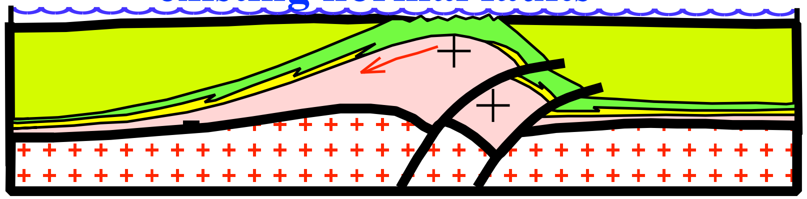
Centripetal Hydrodynamism

Inversion without fault reactivation



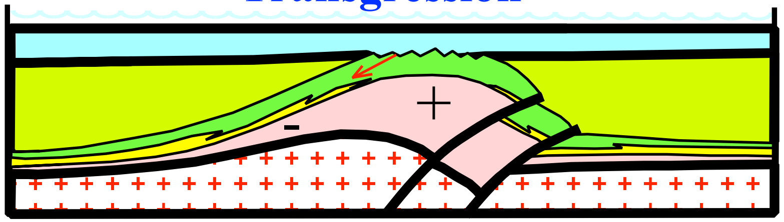
Centrifugal Hydrodynamism

Compression & reactivation of pre-existing normal faults



Centrifugal Hydrodynamism —Trapping

Transgression

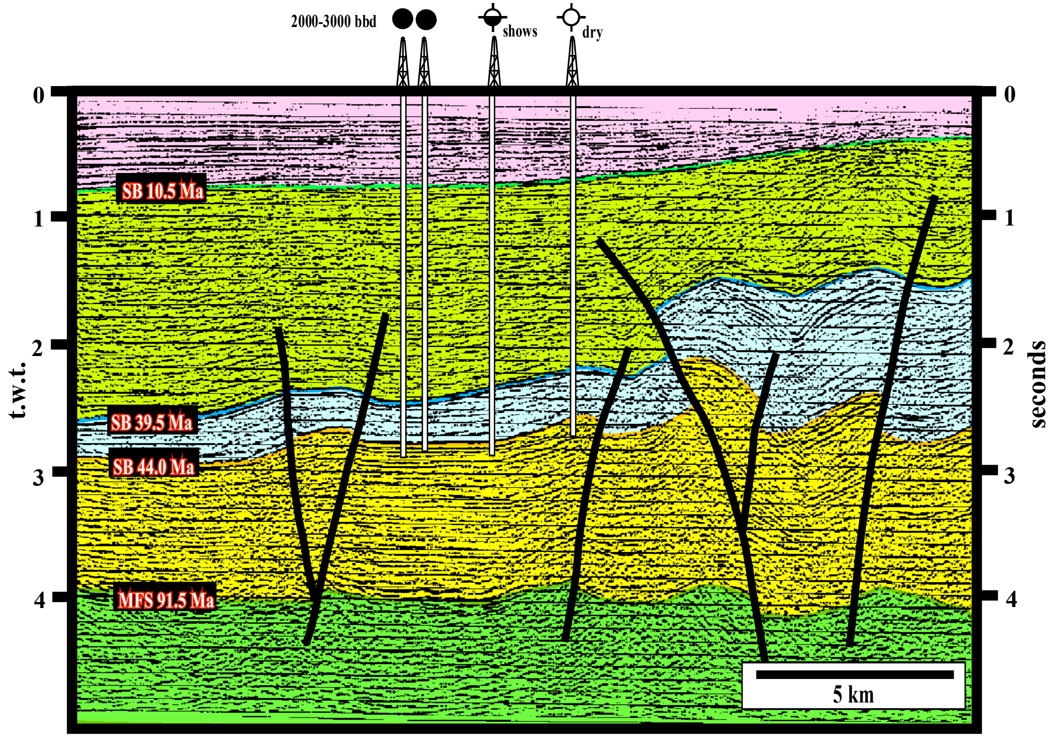


Centrifugal Hydrodynamism — Trapping

During extensional tectonic regimes, the hydrodynamism is centripetal. However, as tectonic inversions took place, the high structural points become low points and the low structural points become high points, and so, centrifugal hydrodynamism becomes preponderant. Subsequently, hydrodynamism being down dip enhances the possibility of non-structural trapping, particularly the stratigraphic traps associated with the transgress if intervals, as illustrated on the next seismic line.

Trapping

The location of the wells with hydrocarbons corroborates the hypothesis that the accumulations are associated with non-structural traps (stratigraphic) in which the trapping is enhanced by a strong down-dip hydrodynamic factor.



F) Classification Traps

The classification of the traps proposed by M. Halbouty is that which can best applies to petroleum exploration. It is particularly useful in the evaluation of remanant petroleum potential. This classification distinguishes two main categories: (i) Structural traps and (ii) Non-structural traps

A- Structural traps

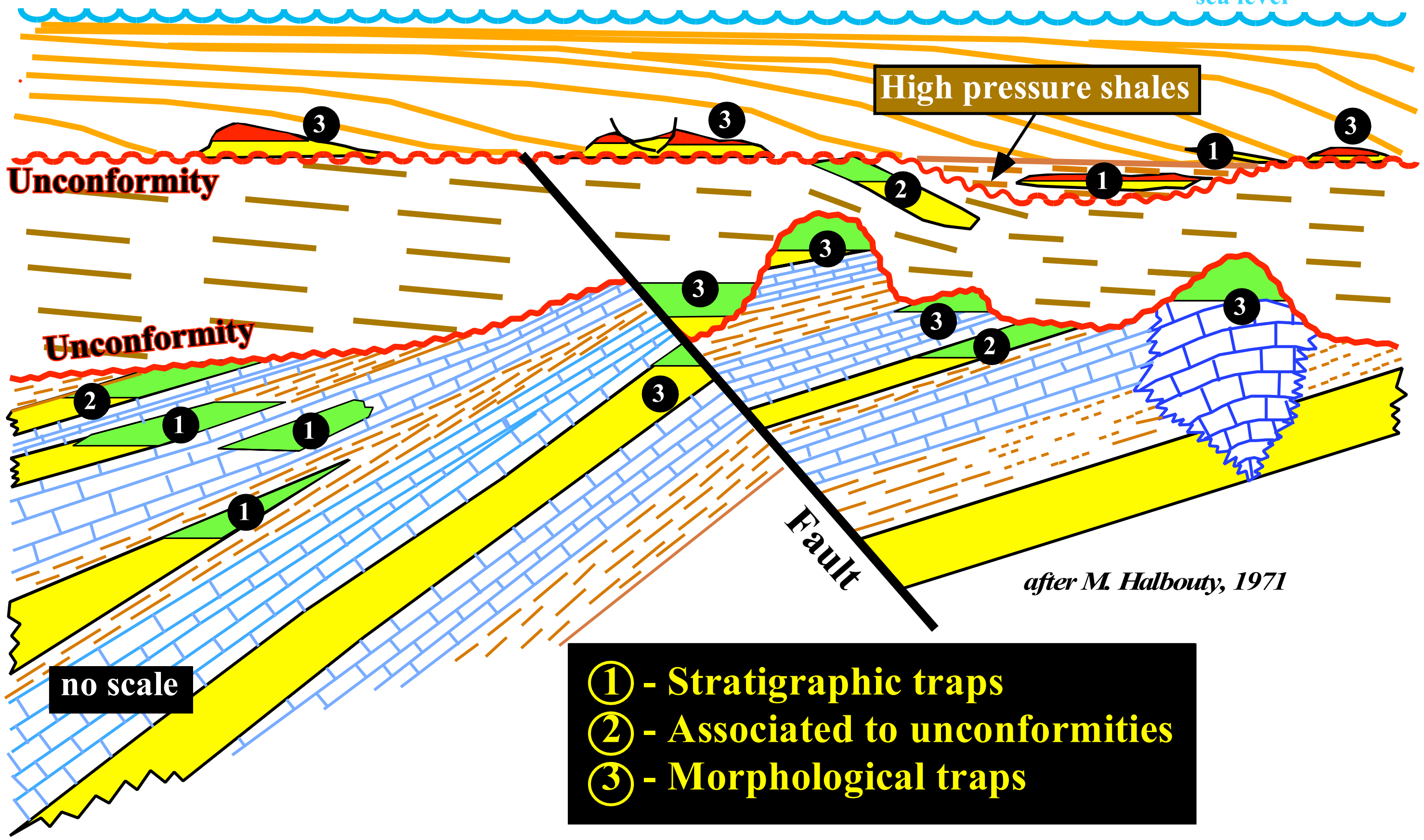
- By definition, these traps are formed after sediment deposition.
- They are characterized by a concave geometry downward of the couple reservoir-seal.
- The reservoir and the seal are, in most cases, composed of a single depositional system, i.e., between the reservoir-rock and sealing-rock, there is any major geological event, such as, an angular unconformity, erosional surface erosion, faults, etc.
- These traps represent about 90% of the giant oil fields in the world (a giant oil field must have at least 70 million tons of reserves (500 Mbbl), while a gas field must have at least 70 Mm^3 ie about 2.5 TCF).

Trapping

- Examples of these traps is often cited in the following fields:

(i) Romachkino in the Urals-Volga, which closed surface of about 3000 km^2 ; (ii) Samotlor, West Siberia, which has a closed surface of 2000 km^2 ; (iii) Ghawar in Saudi Arabia, which has a structural closure of about 2300 km^2 ; (iv) Kirkuk, Iraq, in the foothills of the Zagros, has reserves in excess of 2. 000 Mt ; (v) Kangan, Iran, which has gas reserves of several hundred TCF ; (vi) Gasharan, Iran, whose reserves exceed 1600 Mt ; (vii) El Furrial, Venezuela, Maturin Basin, which has more than 4 billion barrels ; (viii) El Carito, Venezuela, which is the western extension of the field of Furrial ; Cusiana, Colombia, etc.

No-Structural Traps



This diagram shows the different types of non-structural traps. Stratigraphic traps are associated with facies changes. By unconformity and morphological traps are relate to erosion surfaces and faults, as well as to paleo-highs that they induce.

Trapping

B) Non-structural traps

The non-structural traps currently represent about 10% of giant fields in the world. This low percentage should be balanced against the weight of the fields of the Middle East which, in its vast majority are associated with structural traps, and by the difficulty that exploration teams have to recognize them.

Today, these traps are one of the research programs. Many explorationiszs are convinced that reserves to discover are overwhelmingly related to non-structural traps. Most economically profitable non-structural accumulations, are the result of the interaction of various trapping factors. M. Halbouty has divided into three sub-families depending on the predominant geological factor in the trapping

B.1- Stratigraphic traps s.s. ;

B.2- Traps associated with unconformities, and

B.3- Geomorphological traps.

B.1- Stratigraphic Traps

- Stratigraphic traps are basically the result of facies changes that take place during or after deposition.
- When the trap is synchronous with the deposition can be distinguished:

(i) The lateral facies changes permeable to impermeable sediments and
(ii) The pinchout of the reservoir-rocks.
The lateral disappearance of the reservoir-rock can be done by proximal, distal, coastal or marine onlapping.

- As an example of the former (i) iwe can proposed the following fields: (i) Candeias in the Reconcavo basin, Brazil ; (ii) Bell Creek in the Powder River Basin, Montana ; (iii) Jay, in onshore Alabama-Florida.

- As example of the last (ii) the following fields can be cited : (i) Bolivar, Venezuela (Lake Maracaibo and vicinity), whose reserves exceed 15 Gbbls ; (ii) Quiriquiri, Venezuela (1G bl) ; (iii) Pembina, Canada (2G bl).

Trapping

B.2- Traps associated with unconformities

- Traps associated with unconformities are formed when an impermeble layer (clay, salt, etc.), which is the cover of the trap, fossilized an erosional surface and is in direct contact with a reservoir rock located above the unconformity.
- The filling of these traps, that is to say, the migration is more often *per descensum* directly from the source-rock, which also acts as a sealing.
- A migration *per ascensum* is always possible, but it is rare.
- These traps are often associated with tectonic enhanced unconformity horizontalized by the erosive agents.
- They are easily differentiated from the morphological traps located below the erosional surface, that is to say, from the buried hills.
- These traps are the direct result of the stratigraphic cycles; they are present in all petroleum basins.
- Their recognition requires fine stratigraphic analyzes, in particular, by sequential analysis. These analyzes, whether made from seismic data, field or subsurface must imperative start from the stratigraphic cycles associated with eustatic cycles of the first order to those of thelower-order .
- Their approach, like that of any petroleum exploration, is from the general to the particular and not the opposite. The no respect of the hierarchy of stratigraphic cycles in a sequential analysis leads inevitably to failure, that is to say to wrong lithologic predictions.
- The size of the accumulations associated with these traps varies from a few hundred barrels to several billion barrels of recoverable barrels.

A few examples: (1) East Texas (> 5 G bl, USA) ; (2) Prudhoe Bay (> 10 G bl, Alaska) ; (3) Hassi Messaoud (> 20 G bl, Algeria) ; (4) Meillon (Aquitaine) ; (5) Boscan (> 5 G bl, Venezuela) ; (6) Kevin Sunburst (Montana), etc.

B.3- Morphological traps

- One says morphological trap when “ high areas” are fossilized by sediments generally younger and impermeable.
- The “high areas” are, usually, associated, down dip, with unconformities or para-conformities.
- They are produced by geomorphologic processes (ex : cuestas) or depositional processes (ex : reefs, turbidite fans, etc.).
- The traps induced by the relative movements of faulted blocks are called morphological traps by juxtaposition.
    (i) Although their very different origin, the mechanism of trapping and their recognition are very similar.
    (ii) The fault displacements induce “false-high areas” which when closed by juxtaposition form very similar morphological traps are morphologically.

Trapping

- As an example of morphological traps, the following fields can be cited:

(i) Poza Rica (coral, Mexico) ; (ii) Faja d'Oro (coral, Mexico) ; (iii) Redwater (Coral, Canada) ; (iv) Scurry (Atoll, Texas) ; (v) Frigg (turbiditic fans in the North Sea) ; (vi) Balder (turbiditic fans in the North Sea) ; (vii) Marlin And Albacora (turbiditic fans in the offshore Campos, Brazil) ; (viii) President Aleman (canyon in the Faja d'Oro, Mexico).

- As an example of morphological traps by juxtaposition, the following fields are often cited:

(i) Jourdan (Texas) ; (ii) Oklahoma City (USA) ; (iii) Sari (Libya) ; (iv) Bibi Eibat (Russia) ; (v) Faud (Oman), etc.