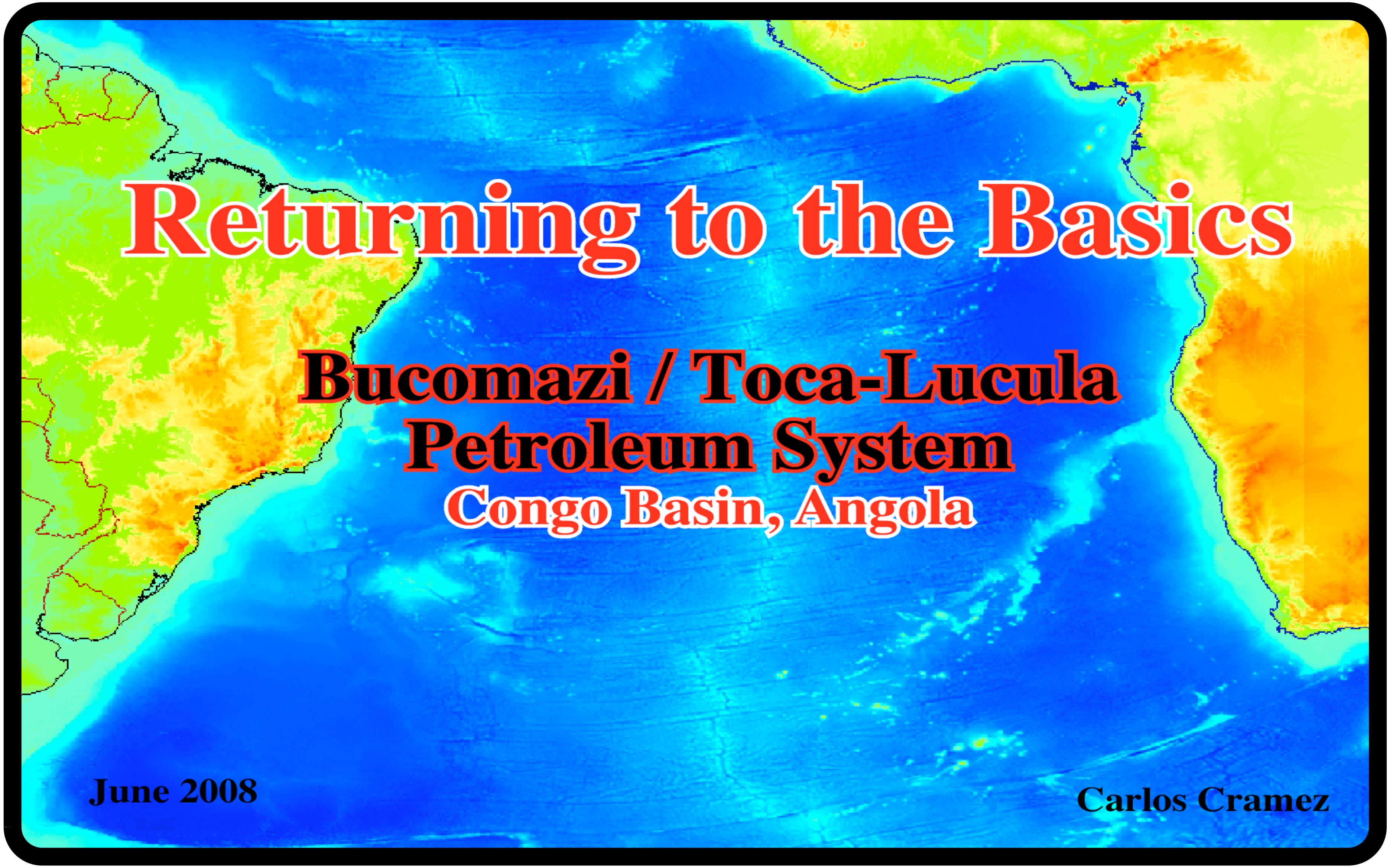
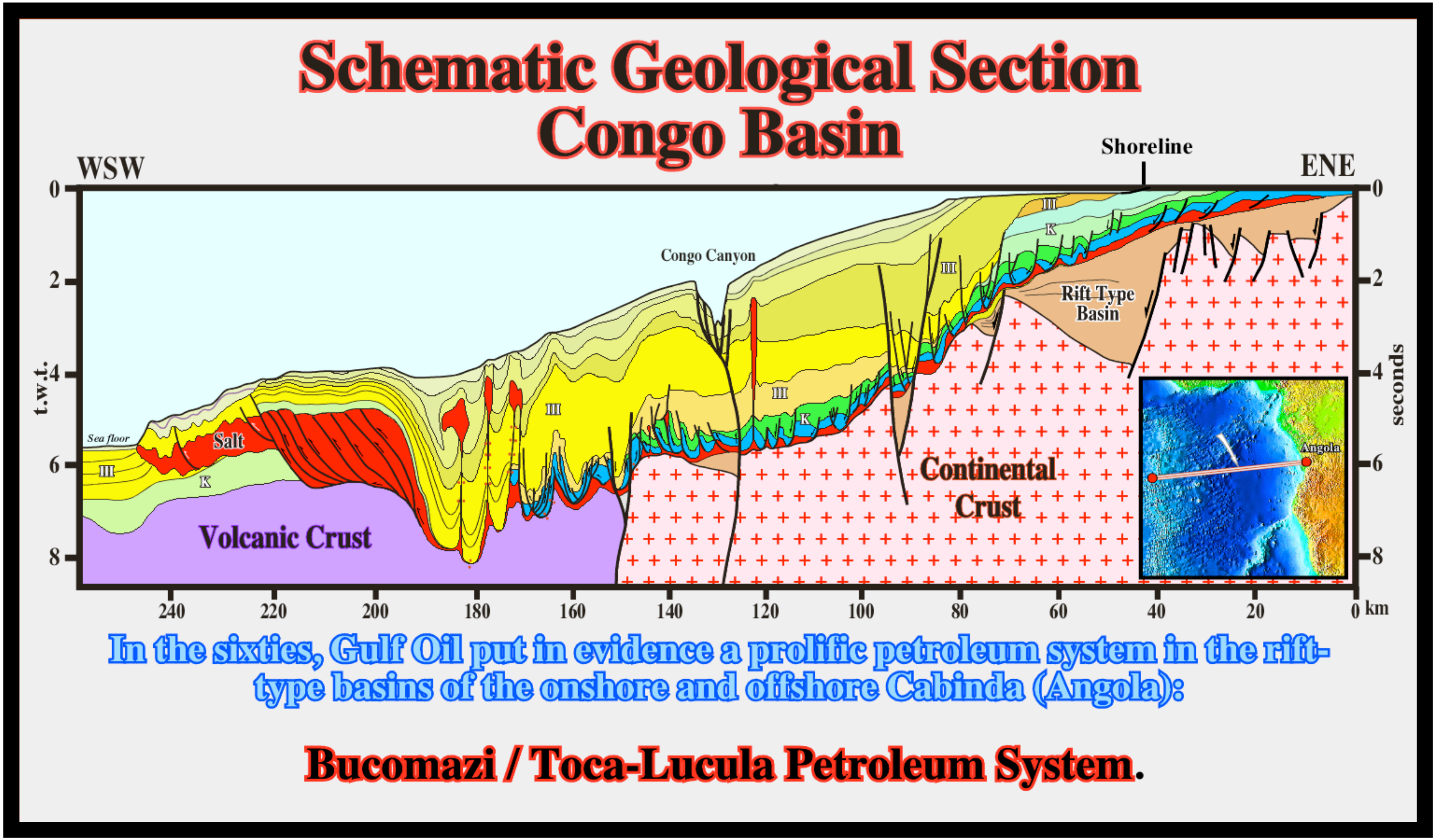

Returning to the Basics
Bucomazi / Toca-Lucula
Petroleum System
Congo Basin, Angola
June 2008
Carlos Cramez



After the oil discoveries found in Santos basin (offshore Brazil) below the salt layer, which apparently seem quite important, few Manager Petroleum Exploration are asking where are the equivalent prospects or fields in offshore Angola, particularly in Congo and Kwanza basins. The answer to this question is quite simple, since, in the 60's, that is to say almost half a century before Petrobràs discoveries, Gulf's explorationists put in evidence, in offshore Cabinda (North Congo basin, northward of Congo River), the Bucomazi / Toca-Lucula Petroleum System, drilling wildcats based just in geological cross-sections and aeromagnetic data. In fact, so far, practically, no wells were drilled in onshore Cabinda after the seismic lines shot in 1972 by Gulf Oil.

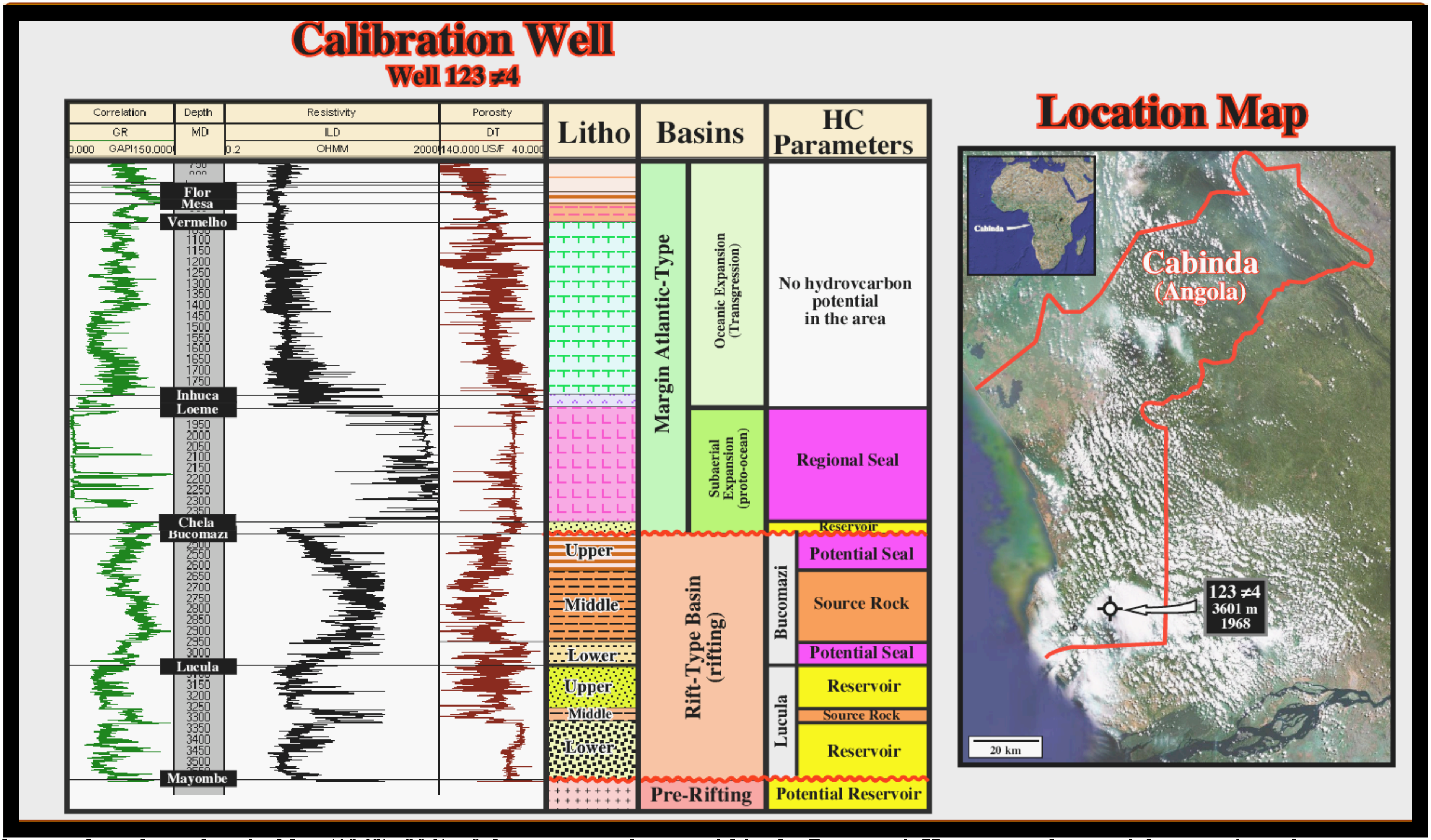
Bucomazi / Toca-Lucula
Petroleum System

A) This petroleum system is Upper Jurassic-Lower Cretaceous and it is entirely located in rift-type basins predating the breakup of the Gondwana and so the subaerial volcanic crust (SDRs).

B) The major source-rock are the organic rich lacustrine shales of the Bucomazi Formation. Organic rich Lucula layers can also be considered as source rocks.

C) The main reservoir rocks are: (i) the non-marine sandstone of the Lucula formation, (ii) lacustrine limestones of the Toca formation and the pre-Cretaceous sediments of the Mayombe formation

The Bucomazi (source-rocks interval) / Toca-Lucula (reservoir-rocks intervals) Petroleum System is a rift-type basin petroleum system, i.e., the main generating petroleum sub-system is formed by the organic rich lacustrine shales of the Bucomazi formation (there is also lacustrine source-rocks the Lucula Formation) and the entrapment-migration petroleum sub-systems is formed mainly by: (i) The non-marine sandstone of the Lucula formation, (ii) The lacustrine limestone of the Toca formation and (iii) The sediments of substratum (Mayombe formation). Both source-rocks and reservoirs are below the breakup unconformity (BUU), which limits the rift-type basins from the sub-aerial vulcanism and the margin sediments.



As illustrated on these electrical log (1968), 80% of the source-rocks are within the Bucomazi. Here, several potential reservoir-rocks were recognized: (i) Lucula sandstones, (ii) Pre-rift sediments (Mayombe), (iii) Chela sandstones and (iv) Toca lacustrine limestones, which have not been traversed by this wildcat). Often, different petroleum systems are considered function of the main reservoir-rock. In the areas where salt welds are absent (vertical migration paths), the salt interval (Loeme) is the regional seal. The Bucomazi shales (source-rocks) and the Lucula shales (secondary source-rocks) can act as sealing-rocks. The post breakup Chela sandstones can be a good reservoir-rock. The trapping mechanism is often absent at such a margin sub-salt level. The Chela sandstones form mainly a migration path toward the border of the basin (asphalts).

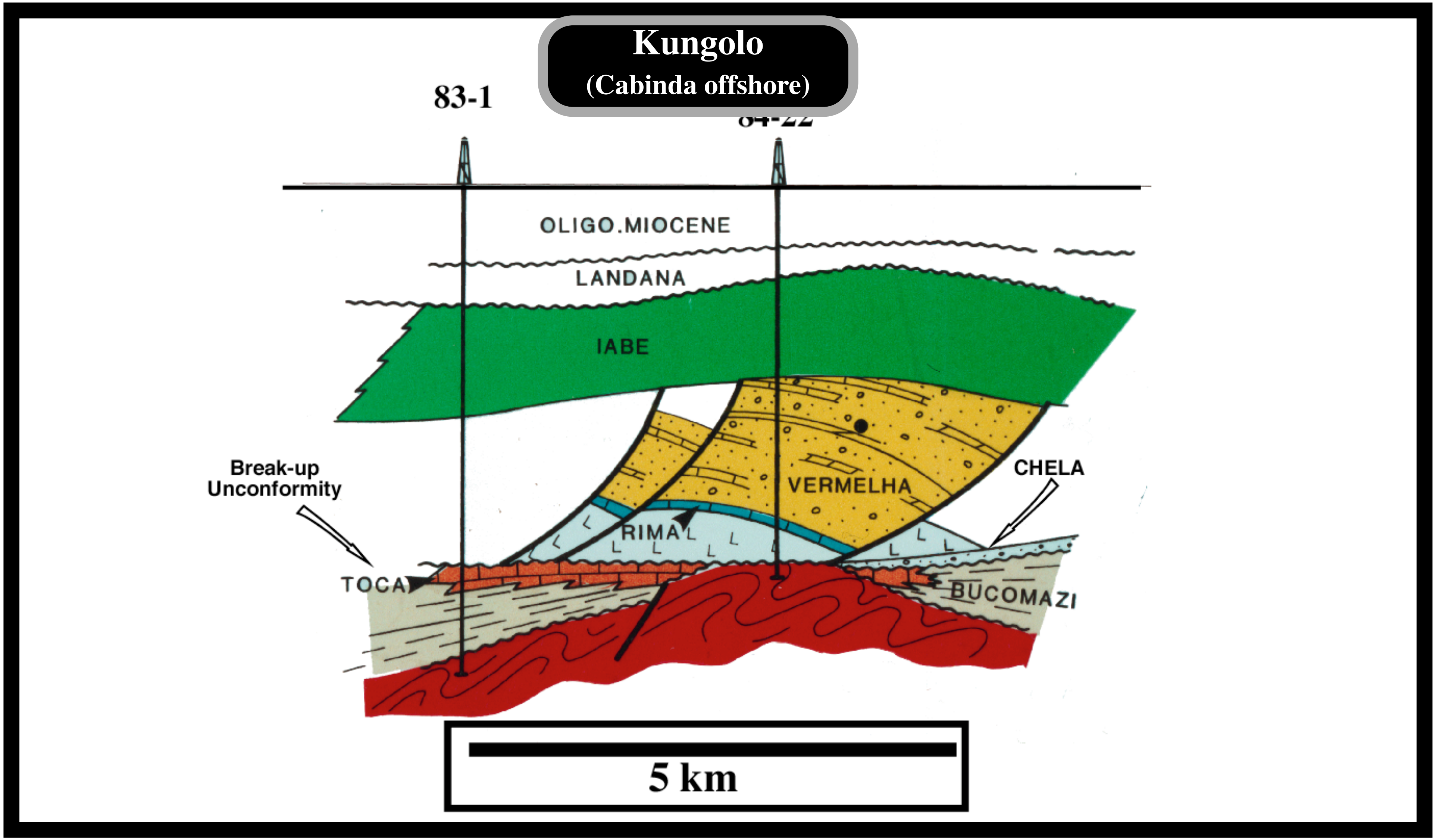
Bucomazi / Toca-Lucula
Petroleum System

D) Several oil fields were discovered in the Toca formation, in conventional offshore, as Takula, Kungolo, Kambala, etc.

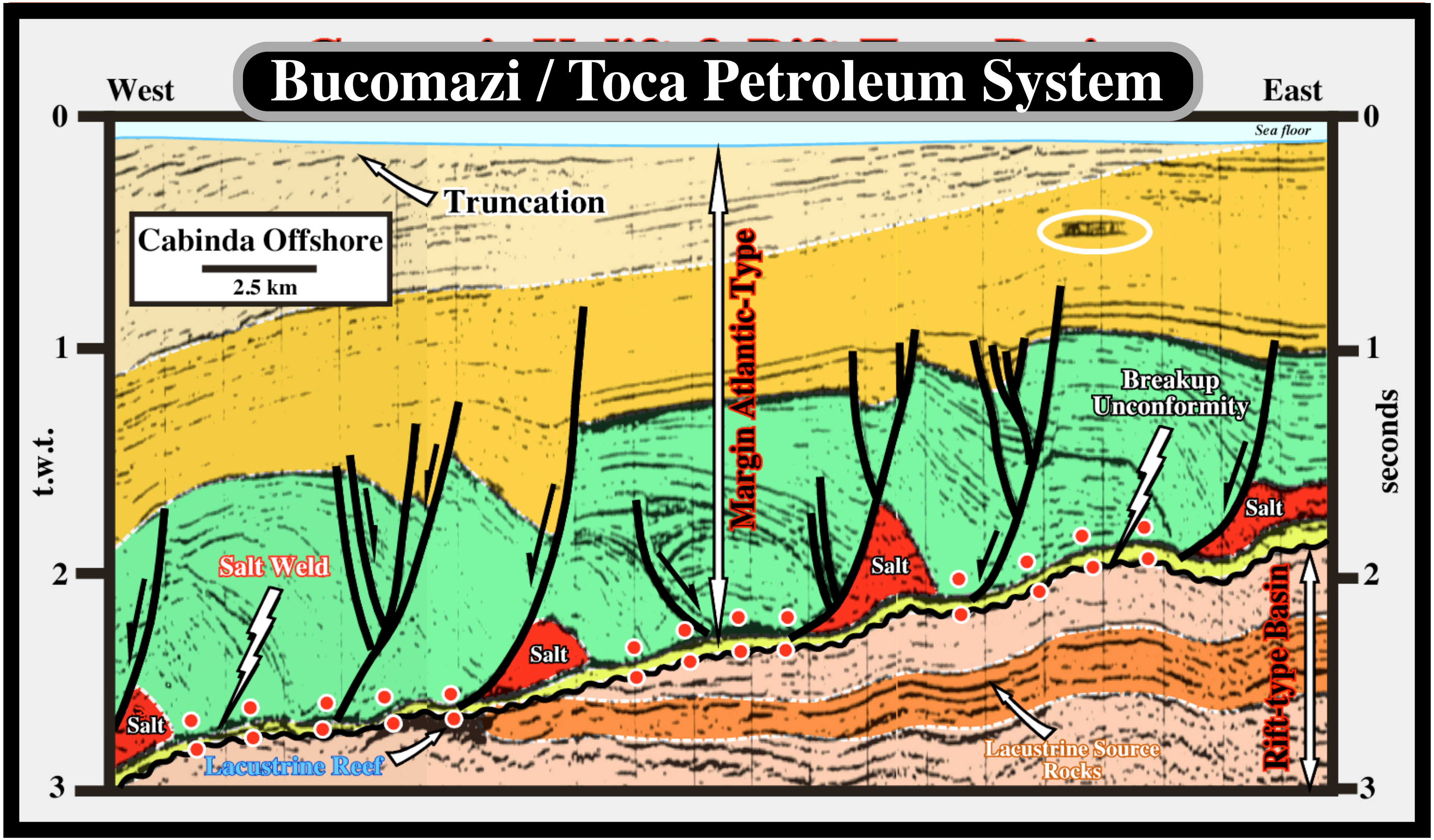
E) At the Kambala, Toca reservoirs are 75 to 300 ft thick and consist of partially to fully dolomitized carbonates that have matrix porosities of 2-10% and very low permeability. Production is mainly controlled by faulting and fracturing. The field contains more than 1 Gb in place, however the cumulative production after 30 years is less than 50 Mb.

F) Lucula sandstone and pre-Cretaceous reservoirs are mainly productive in onshore (Cabinda).

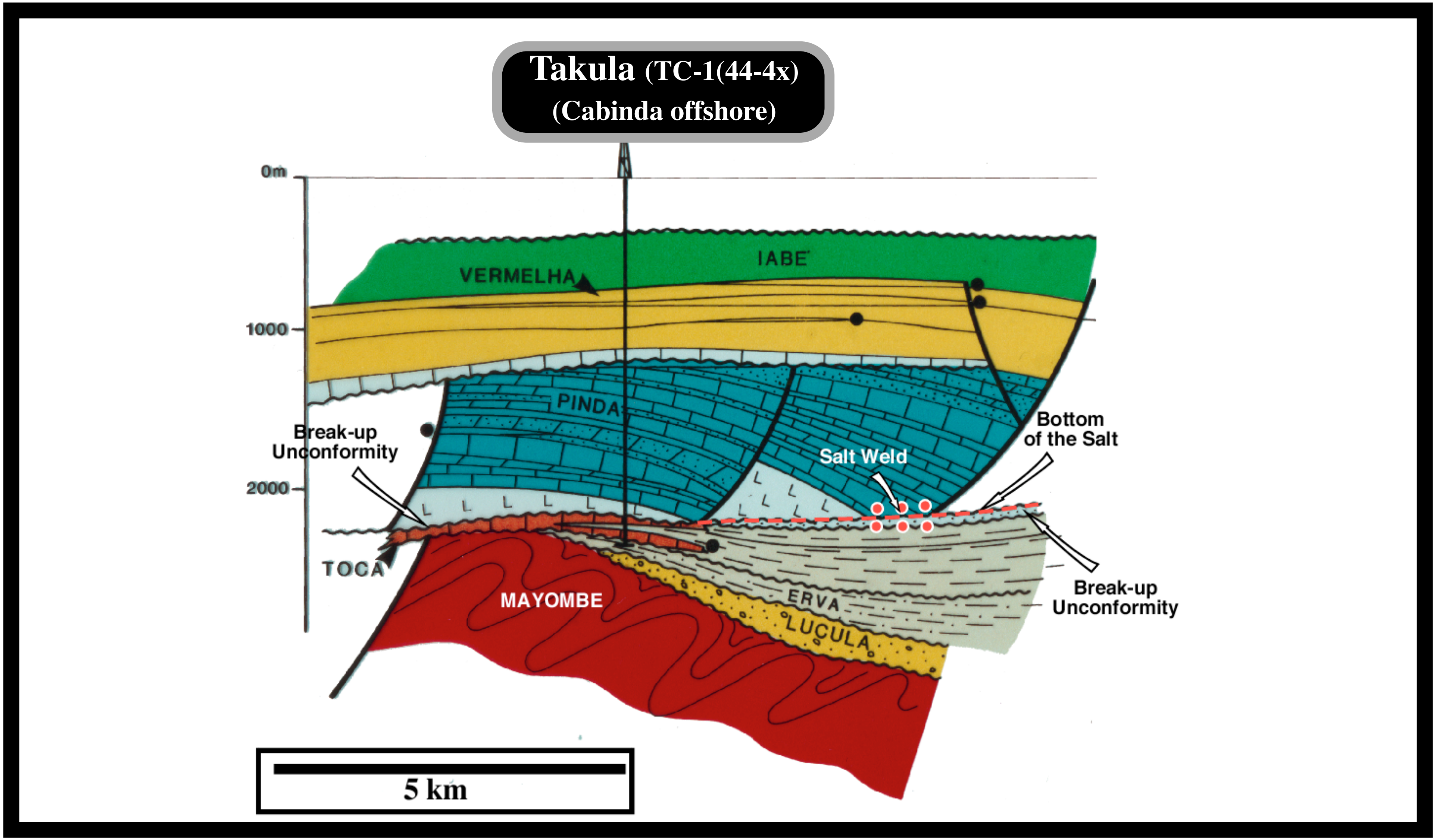
The major hydrocarbon parameters of the Bucomazi /Toca-Lucula petroleum system(s), are not only located below the salt, but also below of the break-up unconformity. Subsequently, when explorationists use the salt as a stratigraphic reference level (supra and infrasalt sediments) misinterpretations are frequent. Indeed, locally, potential source-rocks can develop within the Chela formation, i.e., below the salt but above the break-up unconformity. They are margin sub-salt and not rift-type basin source-rocks. Explorationist must avoid to speak in sub-salt or infra-salt source rocks. In Brazil, for instance, the source rocks of Tupi discovery (Santos basin) and Roncador field (Campos basin) are both sub-salt, but in Tupi they are within the rift-type basin what is not the case in Roncador.



This tentative interpretation of a seismic line of the conventional offshore of Cabinda (no vertical scale for confidential reasons) illustrates the Bucomazi/Toca-Mayombe petroleum system (s). In the beginning of the exploration, i.e., in the 60's, without seismic data, the main targets were the structural highs of the infrastructure (Mayombe formation). The Toca reservoirs (lacustrine limestones) were found by serendipity as suggested in this tentative (the target was the Mayombe). Note the break-up unconformity and the location of the Toca and Chela formations. The Toca is within the rift-type basin and the Chela at the base of the margin. Both are sub salt, but they are in sedimentary basins with completely different geological histories.



On this old seismic line shot by Gulf Oil, the breakup unconformity (BUU) is evident. It is slightly tectonically enhanced. It corresponds to an erosional surface as suggested by the rift-type basin reflection terminations. Toplaps of Toca formation (in grey) and of lacustrine source-rock interval (in brown) a readily recognized. The BUU should not be confused with the "bottom" of the salt (top of the Chela, yellow), which corresponds to the salt induced tectonic disharmony. The deformation of the sediments above and below of the tectonic disharmony is completely different. The lateral salt flowage created several salt welds and depocenters in the margin by compensatory subsidence. All normal faults associated with salt tectonics die at the tectonic disharmony. The wave geometry of the rift-type sediments correspond to seismic artifacts (lateral velocity changes).



On this tentative interpretation of a detail of a seismic line of the conventional offshore Cabinda (Angola), the rift-type basin petroleum system is clearly depicted. The potential reservoir-rocks, i.e., the Toca, Lucula and Mayombe formations are easily recognized. The unconformities identified within the rift-type basin strongly suggest different rifting phases (the same happens in Tupi area, in Brazil). The breakup unconformity is readily placed, as well as the bottom of the salt. In absence of the Chela sandstones (over the structural highs of the basement), the break-up unconformity and the bottom of the salt (tectonic disharmony) are coincident. The oil shows recognized by drilling are related to the Bucomazi, even those found in the Pinda and Vermelha formations. The organic mater of Iabe source-rocks (margin) seems, here, to be immature.

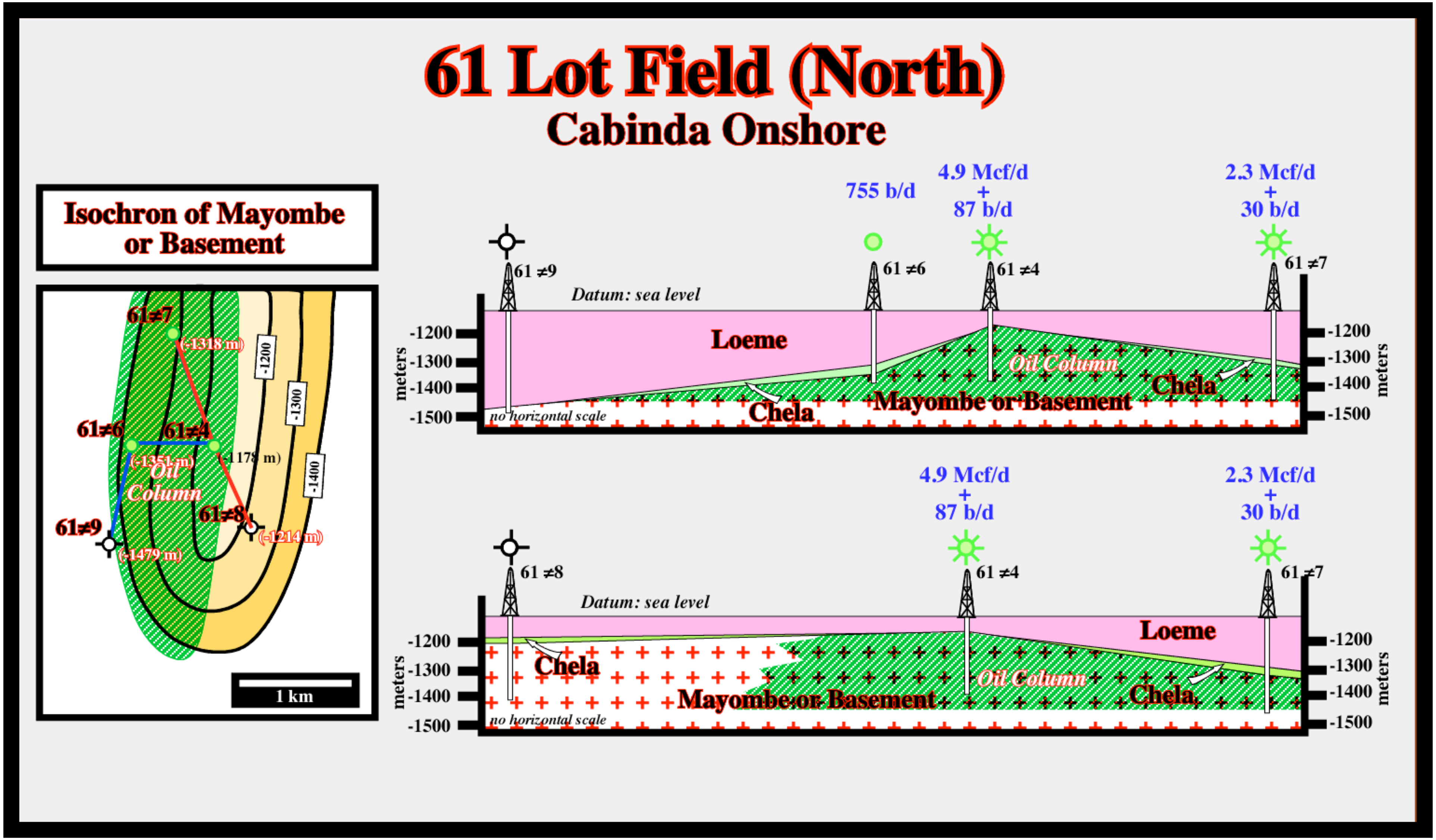
Bucomazi / Toca-Lucula
Petroleum System

G) In the onshore, till 1968, all exploration wells were located on gravimetric maps without seismic data. Gulf was looking for the shallow highs of the pre-Cretaceous (Mayombe Formation).

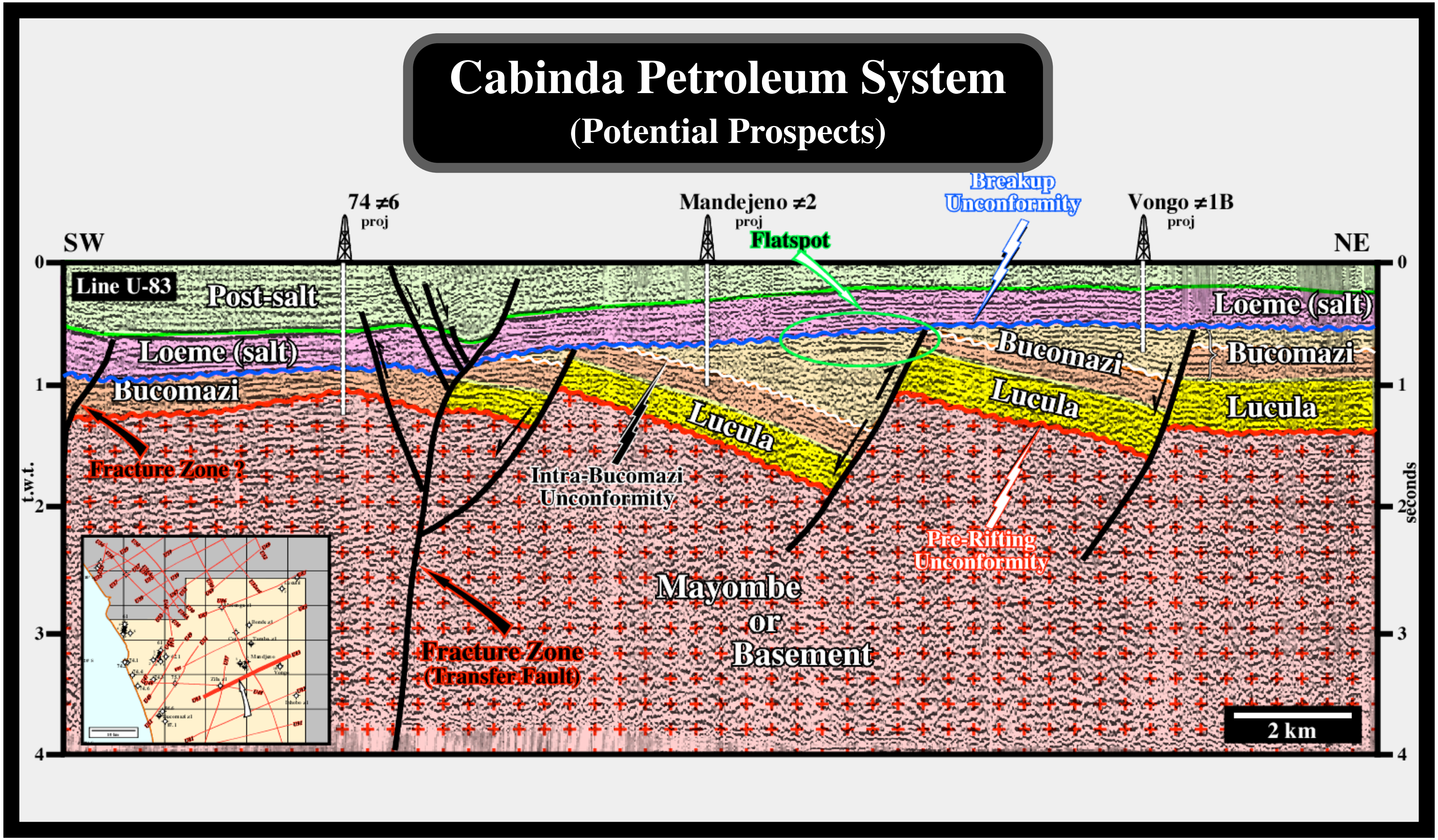
H) An wide seismic grid was shot in 1972. However, for different reasons, exploration stopped in onshore. No wells were drilled since 1968. Gulf Oil concentrated its exploration effort in conventional offshore, particularly after Malongo discovery (post salt).

I) Onshore exploration resumed lately, in southern part of Cabinda onshore and a new round will be announced soon.

In onshore Cabinda, all petroleum exploration was carried out without seismic data. All wells targeted always the structural highs of the substratum (Mayombe formation). Indeed, the Mayombe sediments are a petroleum basement. However, when they are faulted and fractured, they can be considered as an alternative reservoir-rock. In favorable cases, the Toca reservoir (lacustrine reservoirs) can be found overlying the Mayombe highs, but, generally, its extent is relatively small. On the contrary, the Lucula sandstone reservoirs, which, by far, have the best petrophysical reservoir characteristics, are often absent, by non deposition, on the structural highs of the Mayombe. Recently, (2006 ?), at least one wildcat was drilled in southern part of onshore Cabinda taking into account seismic data.



In onshore Cabinda, the oil accumulations found by Gulf Oil using just gravimetric data (structural highs of the Mayombe) are not associated with structural traps (four way dip closure), but rather with non-structural traps (stratigraphic and morphological by juxtaposition). In 61 Lot Field (North), only the wells drilled in western flank of the Mayombe high found hydrocarbons. The presence of hydrocarbons is related mainly with local variations of the petrophysical reservoir characteristics of the Mayombe (fracturing) than with a closed area. The Chela reservoirs (margin sub-salt sandstones) are often absent on the top of the buried hills and tilted-blocks. The sealing-rock is the salt that here is relatively thick and continuous.



This tentative interpretation of a seismic line (1972) shot in the central part of the Cabinda onshore, illustrates the Bucomazi/Lucula petroleum system. It strongly suggests that the remaining petroleum potential is associated with morphological traps by juxtaposition. The Lucula reservoirs and the Bucomazi source-rocks are easily recognized as well as the salt layer. The breakup unconformity (BUU) can be picked all along of the line. It corresponds to the bottom of the salt, since the thickness of Chela formation is below the seismic resolution. Take into account that the eastern part of the Congo basin was significant uplifted (1.5 - 2.5 km). The Bucomazi source-rocks reached the oil window before being uplifted to the present depth.

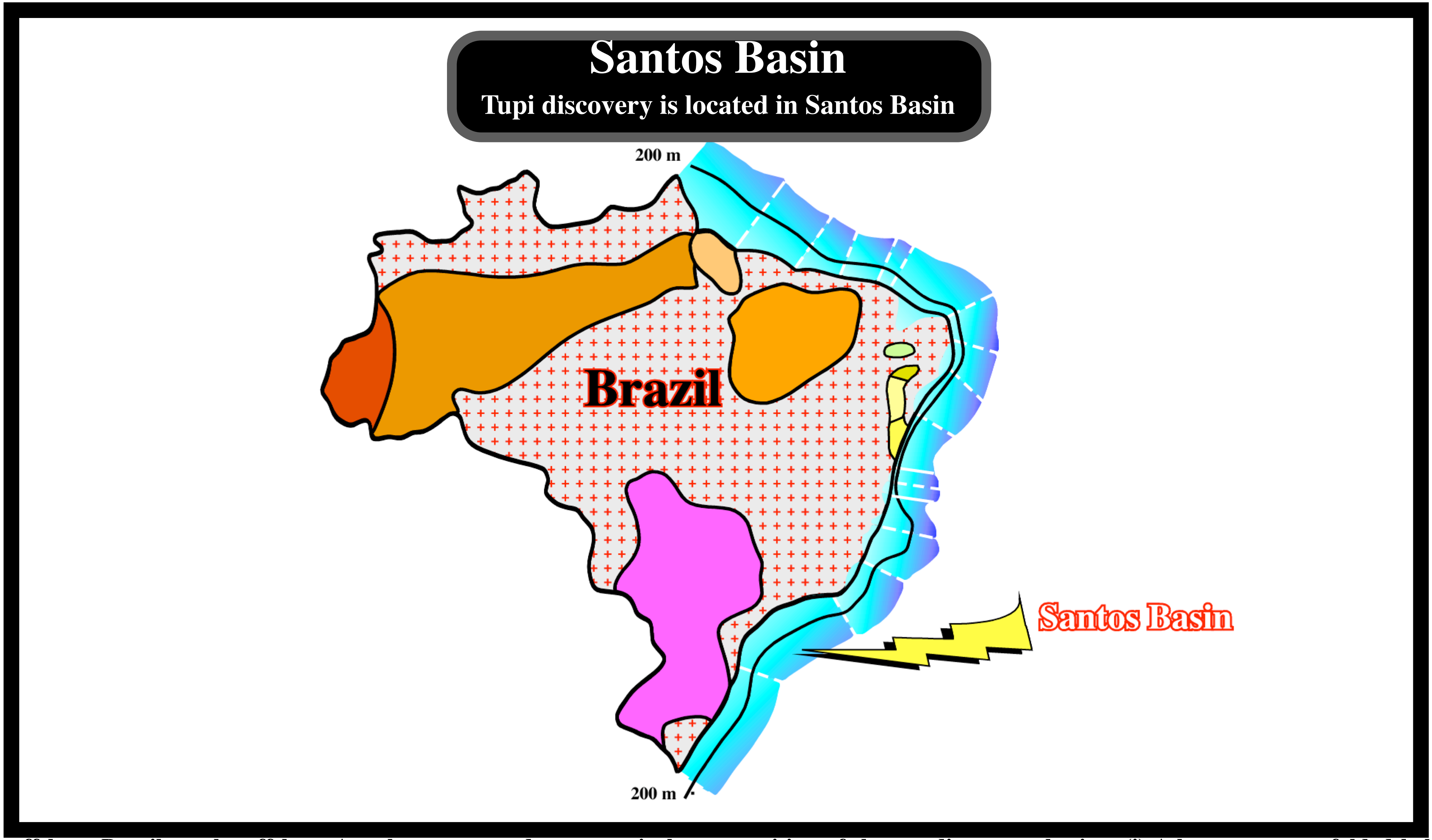
Bucomazi / Toca-Lucula
Petroleum System

J) Since Angola gained independence from Portugal and particularly in the 80's, exploration concentrated in offshore were a other petroleum system were found.

K) The generating petroleum subsystem of the new petroleum systems is related to the transgressive Cenomanian-Turonian sediments (Iabe formation). The reservoir rocks are either Cretaceous carbonates and clastics or Tertiary turbidite sandstones

L) When the easy, cheap and successful exploration in offshore Angola (just drilling seismic amplitudes) approaches the end, the Tupi discovery, in Santos basin (Brazil), oblige a reevaluation of the old Bucomazi / Toca-Lucula petroleum system.

As presently, the security in onshore Cabinda are quite good, a lot of oil companies are interested in restart the exploration to test the petroleum potential of the rift-type basins petroleum systems, i.e., (i) Bucomazi / Lucula, (ii) Bucomazi / Toca and (iii) Bucomazi /Mayombe. To end the first part of this talk, do not forget that in onshore Cabinda: 1) The petroleum exploration stopped in 1968 after discovery of several small fields, 2) All wells (around 80) drilled by Gulf Oil were located without seismic data, 3) All wells targeted structural highs of the basement, 4) There are no structural traps (conjecture corroborated by the seismic data), 5) The potential traps are morphological by juxtaposition (tilted-blocks) and morphological (Toca lacustrine limestones), 6) The remaining reserves can reached 2-3 Gb (2-3 10^9 barrels of oil).



The offshore Brazil, as the offshore Angola, corresponds to a vertical superposition of three sedimentary basins: (i) A basement or a folded belt, (ii) Rift-type basins and (iii) An Atlantic-type divergente margin, i.e., a divergent margin developed in a geological setting dominated by extensional tectonic regimes. The generating petroleum subsystems responsible for the accumulations found are infra-salt. But, as said previously, they are located above the breakup unconformity (BUU). They correspond often to hypersaline lacustrine source-rocks roughly associated with the salt layer. Before Tupi discovery, just in Reconvaco basin (onshore in yellow), the source-rock interval was located below the breakup unconformity, in a rift-type basin.

Santos Basin

A) As all other South Atlantic Basins, Santos basins correspond to the vertical superposition of two sedimentary basin types: (i) Mesozoic rift-type basins and the Meso-Cenozoic western South Atlantic margin, in which a thick salt layer was deposited.

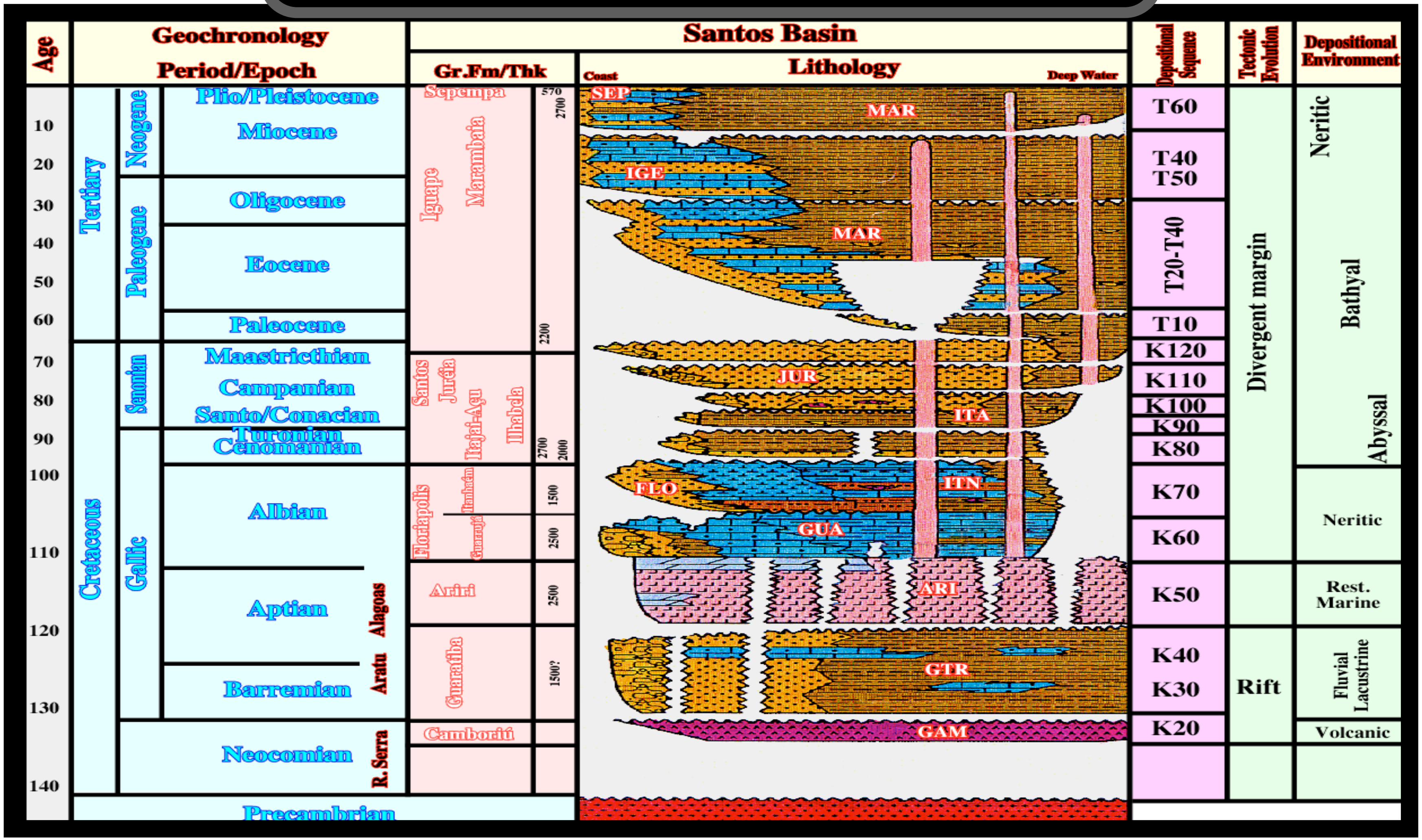
B) Geologically, it is limited by two structural highs: (i) Florianopolis at the south and Cabo Frio at north. Geographically, it corresponds to the Rio de Janeiro, São Paulo, Paraná and Santa Catarina offshores.

C) The total area of the conventional offshore is around 200.000 km^2. In the western portion of the basin, i.e., landward of the 80 m water depth, the hydrocarbon potential is inexistent. The rift-type basins and the evaporites are absent.

To better understand a petroleum system, which is a genetic relationship between a source-rock and reservoir-rock, one must consider the realms of subsidence, i.e., the stacking of sedimentary basins composing the area. Indeed, the exploration approach is not the same when the source-rock interval (the principal) is located within the rift-type basins or in the margin. This is particularly true in salt basins having a mature salt tectonics. Similarly, when the source-rock interval is below the salt layer, it is quite important to see if it is below or above of the breakup unconformity (BUU), which individualizes the rift-type basins from the divergent margin.

Stratigraphic Column

(Santos Basin)



As you can see in this stratigraphic column, conventionally brazilian geologists consider, and have always considered, within the Guaratiba formation all sediments between the bottom of the salt and vulcanism. Actually, such stratigraphy is readily falsified (refuted). The vulcanism, is subaerial and corresponds to the lava-flows (seaward dipping reflectors) set up immediately after the breakup of the lithosphere. In other words, the volcanism separates the rift-type basins, which predate the breakup, from the margin, which postdate de breakup. A major unconformity, the breakup unconformity (BUU), which correspond to the breakup of the Gondwana), lies within the Guaratiba formation, which should be imperatively be subdivide at least in two different geological formations.

Santos Basin

C) About 115 exploratory wells have been drilled in the basin mainly targeting relatively shallow post-salt clastic objectives.

D) The source-rocks are supposed to be the sub-salt Lower Cretaceous lacustrine shales of the sub-salt Guaratiba Formation, which include rift-type basin and margin sediments (see later).

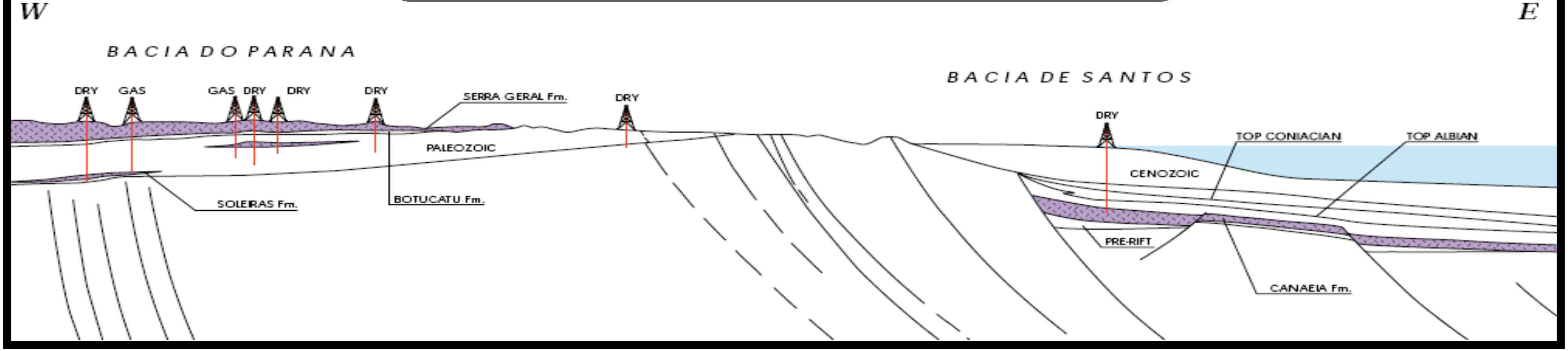
E) The main reservoir-rocks are the Lower-Middle Albian carbonates of the Guaruja Formation and Turonian turbidite sandstones of the Ilhabela Member of the Itajai-Acu Formation.

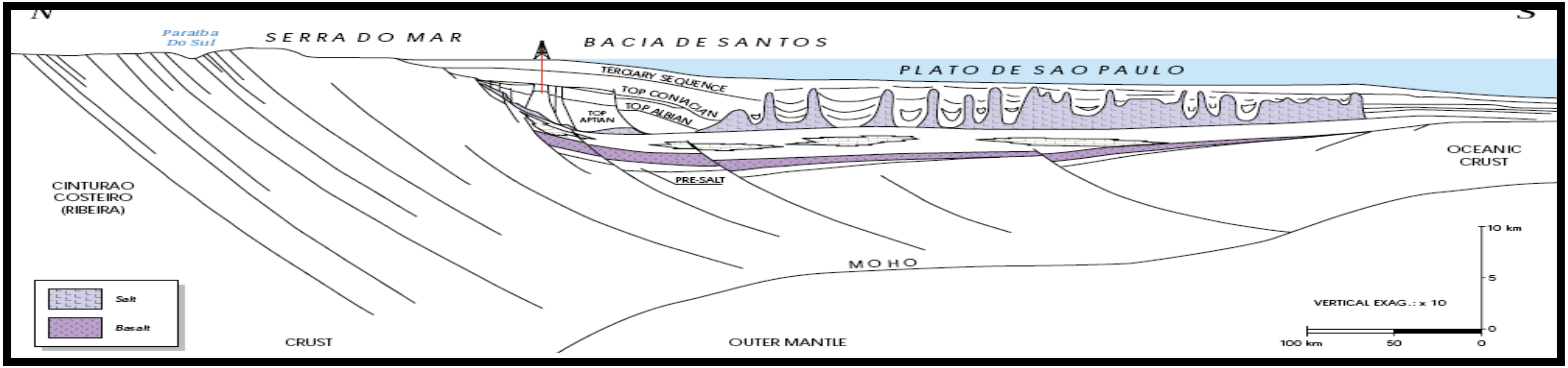
D) Cumulative production is about 0.26 Tcf from Merluza Field (0.30 Tcf ultimate recovery) and 42 Mb from the Coral-Tubarão-Estela do Mar-Caravela Field (228 Mb +0.25 Tcf ultimate recovery).

Before the Tupi discovery, in Santos basin, the exploration results were not very good. The main reservoir-rocks were the supra-salt Albian carbonates and the source-rocks were the organic rich hyper-saline lacustrine shales of the Guaratiba formation, considered as equivalent of the Lagoa Feia source-rocks (Campos basin). The conventional source-rocks are associated with the margin and not with the rift-type basins. They are not equivalent to the Bucomazi source-rocks of the onshore Cabinda (Angola). In spite of the fact that M. Webster (Petrobràs), in 1998, recognized that all sediments overlying the subaerial vulcanism postdated the breakup unconformity (BUU), Petrobràs' geologists insist to considered the salt layer as a major the stratigraphic element disregarding the BUU, which separates the rift-type sediments from the margin sediments and sub-aerial vulcanism (SDRs).

Regional Geological cross-sections

(Paraná - Santos Basin)

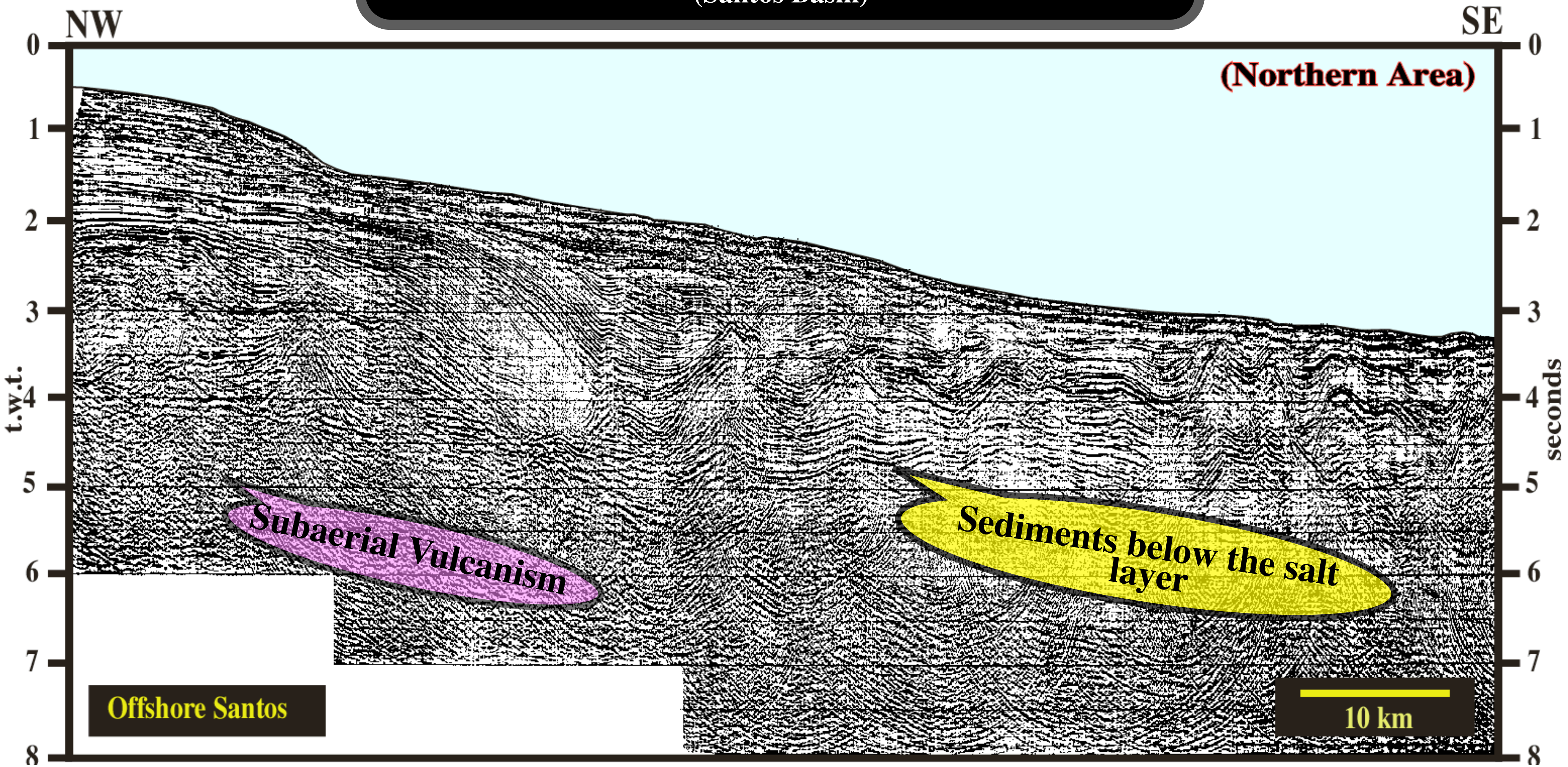




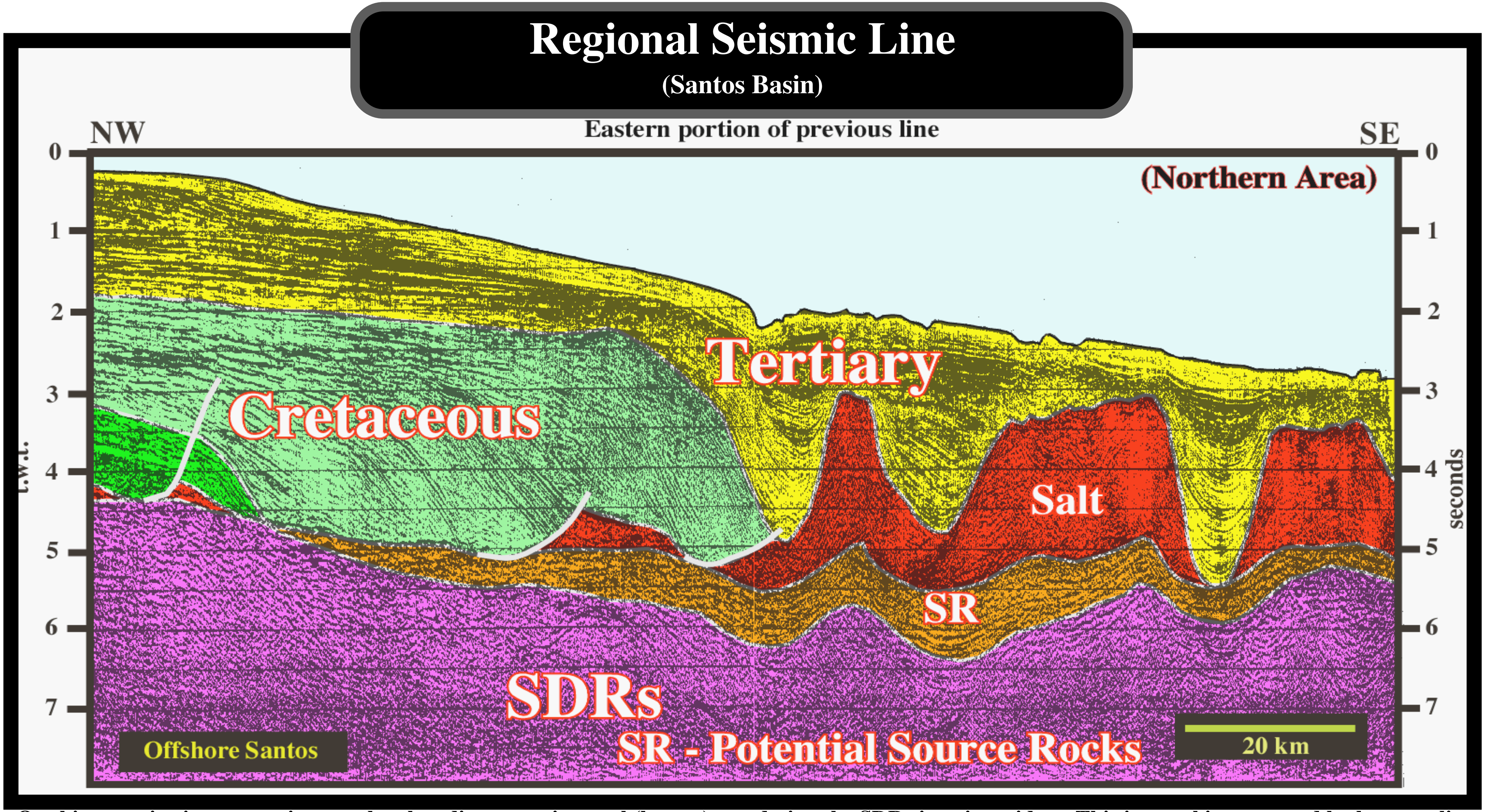
These two perpendicular cross-sections clearly depict the erroneously interpretation and meaning of the subaerial vulcanism of Petrobràs geologists. They are in contradiction with all publications and seismic data proposed by M. Mohriac and Total's explorationists. The large intrusion province (LIP) of Parana basin is correlated with the SDRs (Seaward Dipping Reflectors) of Santos. The volcanism is the infrastructure of the pre-rift sediments (upper section) and lies in the pre-salt interval (lower section), which is completely wrong as illustrated later. The SDRs (subaerial vulcanism), as we will see later fossilizes the breakup unconformity (BUU), individualizing the rift-type basins (differential subsidence) from the margin (thermal subsidence).

Regional Seismic Line

(Santos Basin)



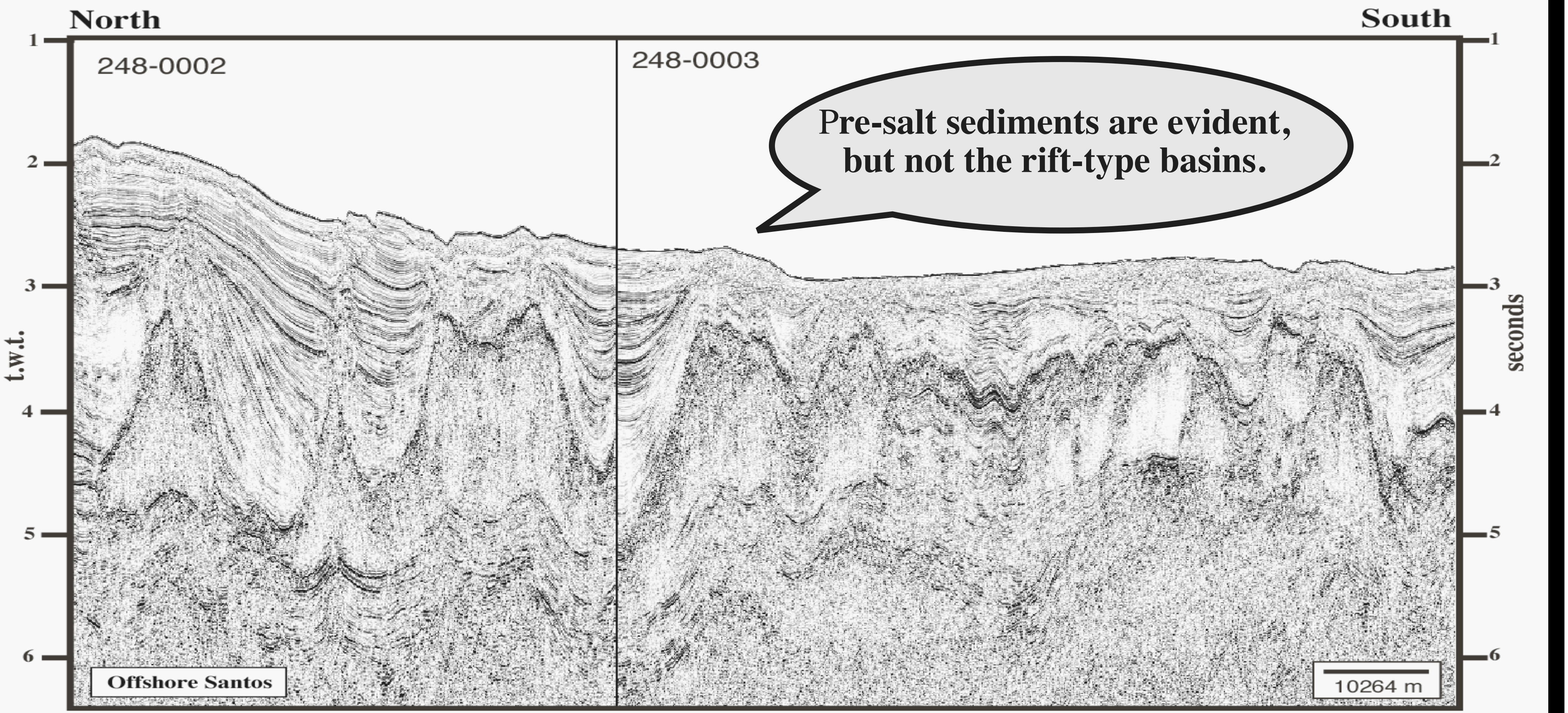
On this seismic line from offshore Santos (Brazil), the seaward dipping reflectors (SDRs), i.e., the subaerial vulcanism postdating the breakup of the Gondwana's lithosphere, is overlain by margin sub-salt sediments. The breakup unconformity is not visible since it correspond to the base of the SDRS., which can overly either rift-type sediments or the basement. This line contrasts with the regional lines of offshore Angola. Here, and contrariwise to what happen in offshore Angola, the Cretaceous margin sediments are thick and the Tertiary sediments thin. Thus is true except in the mini-basins (salt expulsion basins) where Tertiary sediments can form huge depocenters, as illustrated in the next plate.



On this tentative interpretation, a sub-salt sedimentary interval (brown) postdating the SDRs is quite evident. This interval is composed by hyper-saline lacustrine shales and it corresponds to the conventional source-rocks of Santos basin. It is equivalent to the source-rocks interval of the Campos Basin (Lagoa Feia Formation) and it belongs to the divergent Atlantic margin and not a rift-type basin as it is the case for the Bucomazi formation in onshore Cabinda. Do not forget that wavy geometry of sub-salt intervals is a seismic pitfall created by lateral velocity changes in the sediments overlying the tectonic disharmony (bottom of the salt and salt welds). Note the Tertiary depocenters associated with the salt expulsion basins (mini-basins).

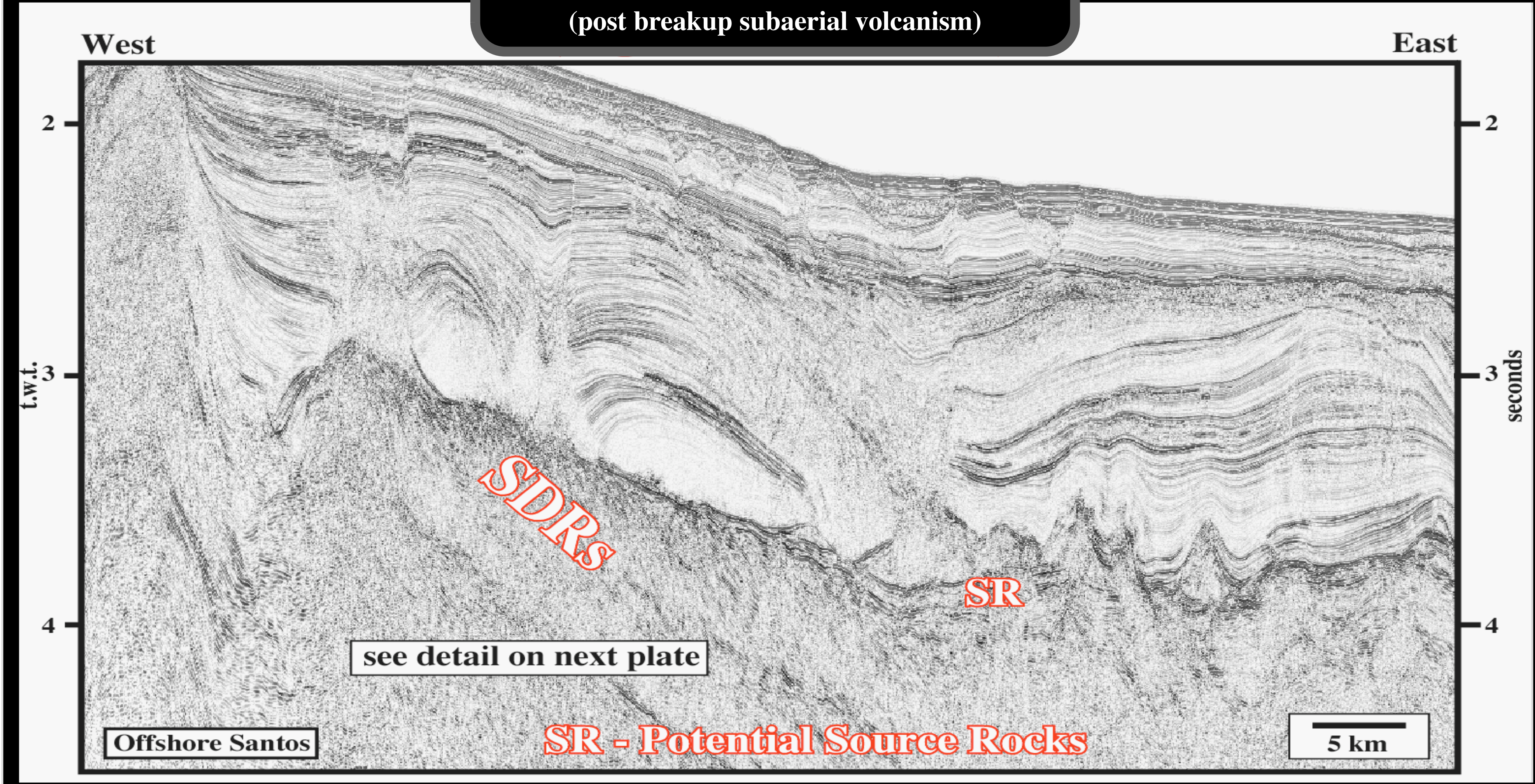
Regional Seismic Line

(Santos Basin)



Again, on this modern seismic line of offshore Santos, sub-salt sediments are evident all along the line. They correspond to margin sub-salt sediments and not to rift-type sediments, i.e., the sediments deposited within rift-type basins created by lengthening of the Gondwana lithosphere before its breakup. They are associated with a regional thermal subsidence rather than a differential subsidence as it is the case for the Bucomazi formation (Cabinda). They dip (slightly) seaward, in contrast to strong landward dip of the rift-type sediments. They likely overly the subaerial volcanism of Santos basin, which in this particularly line is not evident, but the next lines are strongly corroborate such a conjecture.

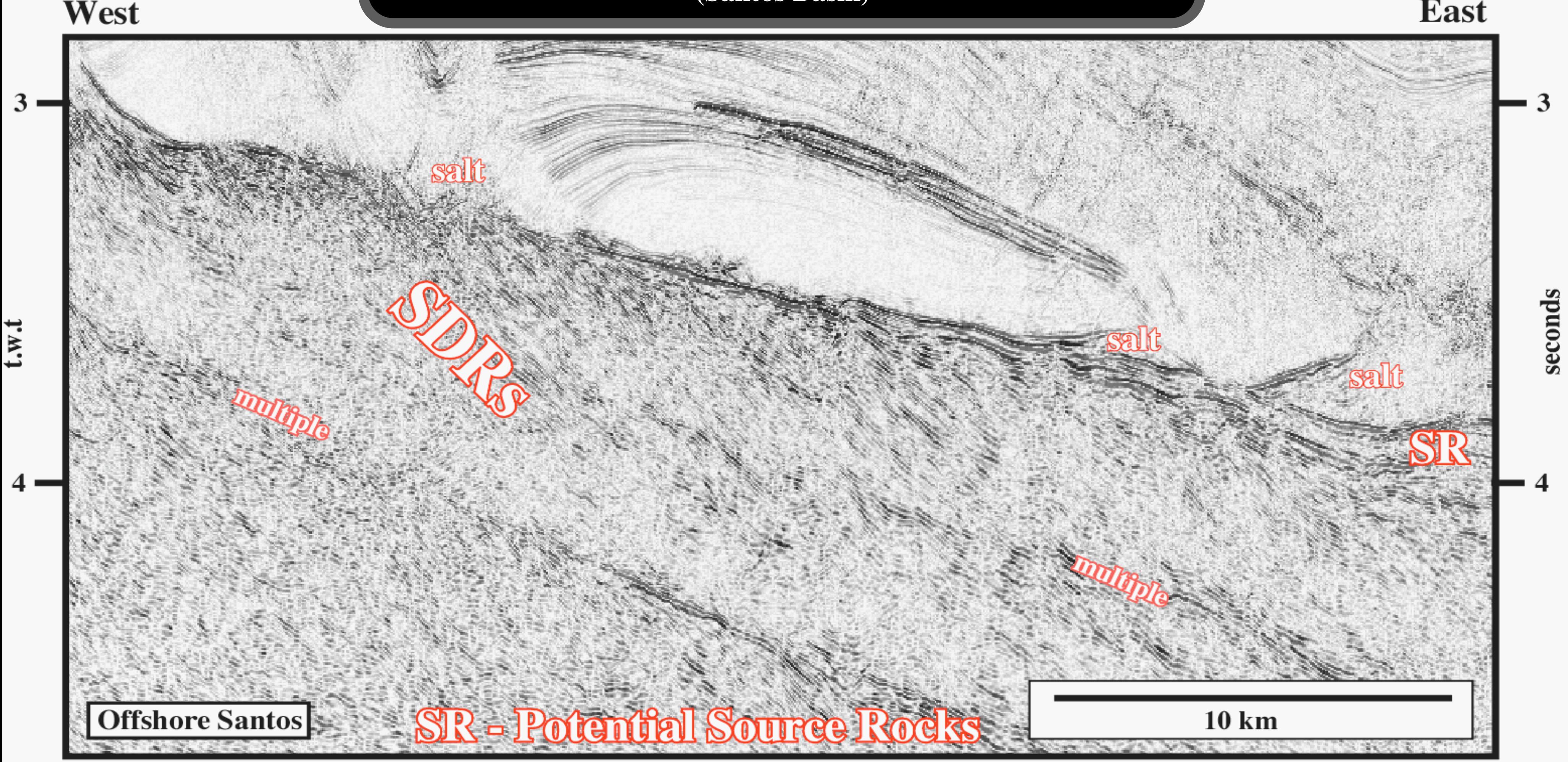
Evidence of SDRs
(post breakup subaerial volcanism)



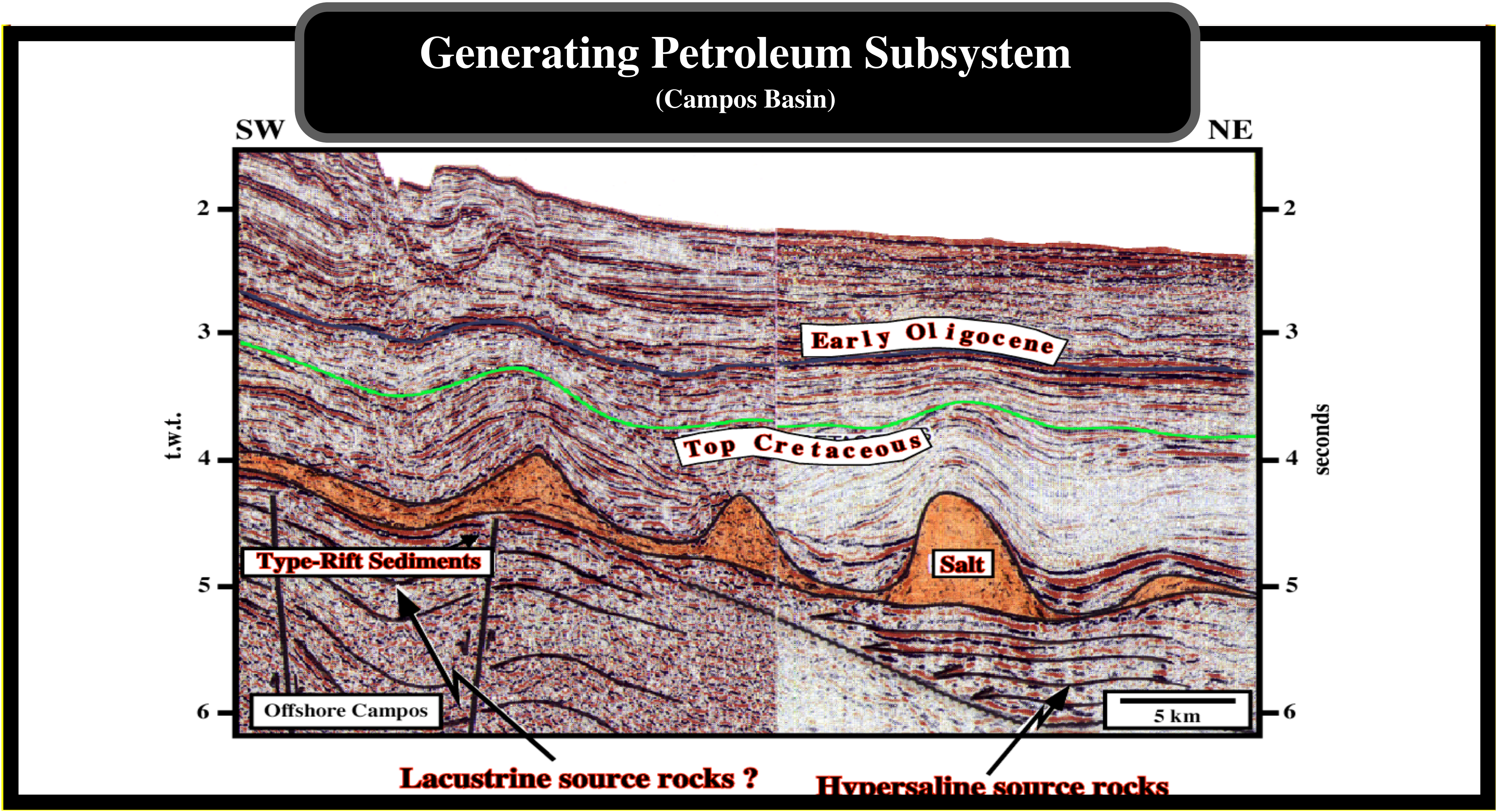
On this seismic line, the pinch-out of the margin sub-salt sediments (conventional source-rocks interval) on the SDRs is quite evident (see close-up in the next plate. No rift-type basins are visible. Taking into account the thickness of the subaerial vulcanism (SDRS), which often overly the distal rift-type basins, the existence of rift-type basin is more likely landward. Contrariwise to the offshore Angola, the thickness of the Cretaceous margin sediments (quite deformed by salt tectonics) is much higher than the overlying undeformed Tertiary sediments (above the tectonically enhanced

Evidence of SDRs

(Santos Basin)

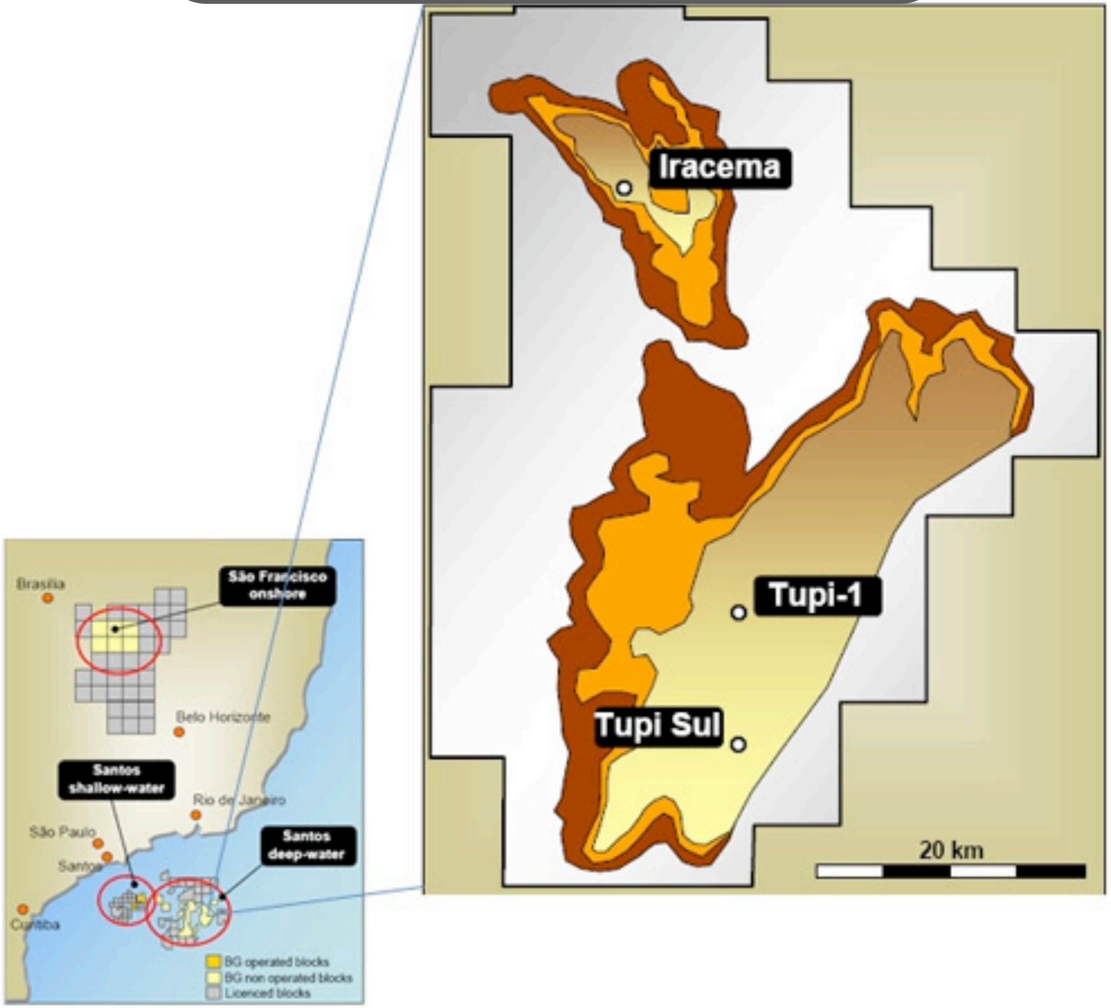


On this close-up of the previous line, the seaward dip of the SDRs and the onlap of the margin sub-salt sediments (conventional source rocks) are here evident. The break-up unconformity (not visible on this line), not visible here, corresponds to the bottom of the SDRS. On this particular line, the SU unconformity, (SDRs unconformity = top of the SDRs) coincides with the tectonic disharmony (bottom of salt or salt welding) in the central and left part of the line. On the right part, the SU is fossilized by the bottom of the margin sub-salt sediments which top coincides with the tectonic disharmony.



Since long time, Total's explorationists consider that the hyper-saline source-rocks of Campos basin are associated with the salt, i.e., with the margin rather than with the rift type basin sediments. Stefano Mora (unpublished data) used this line to illustrate such an hypothesis, but what is interpreted as a rift-type basin can easily be interpreted as SDRs. The margin sub-salt sediments onlap more likely on the SU, that is to say, on the unconformity associated with the top of the SDRS (SU) rather that on the breakup unconformity (BUU). However, the seismic line published by Petrobràs (see later) to illustrated the Tupi discovery, readily corroborates the conjecture advanced by S. Mora when he was a Total's explorationist.

Tupi Discovery
(Santos Basin)



Tupi discovery is located in the deep-water of Santos basin southward of Iracema. According to the published data from Petrobràs, in which the wells are projected, the discovery seems to correspond to the highest area (or NNW flank) of a buried hill bordering a rift-type basin. The reservoir-rock seems to be mainly associated with lacustrine limestone probably similar to the lacustrine limestones of the Toca formation recognized in North Congo basin (Cabinda offshore. The distance between Tupi ≠1 and Tupi South is around 10 km. It appears that such a distance is too big to assume that the petrophysical characteristics of the reservoir-rocks (lacustrine limestones) are constant all along.

Tupi Petroleum System

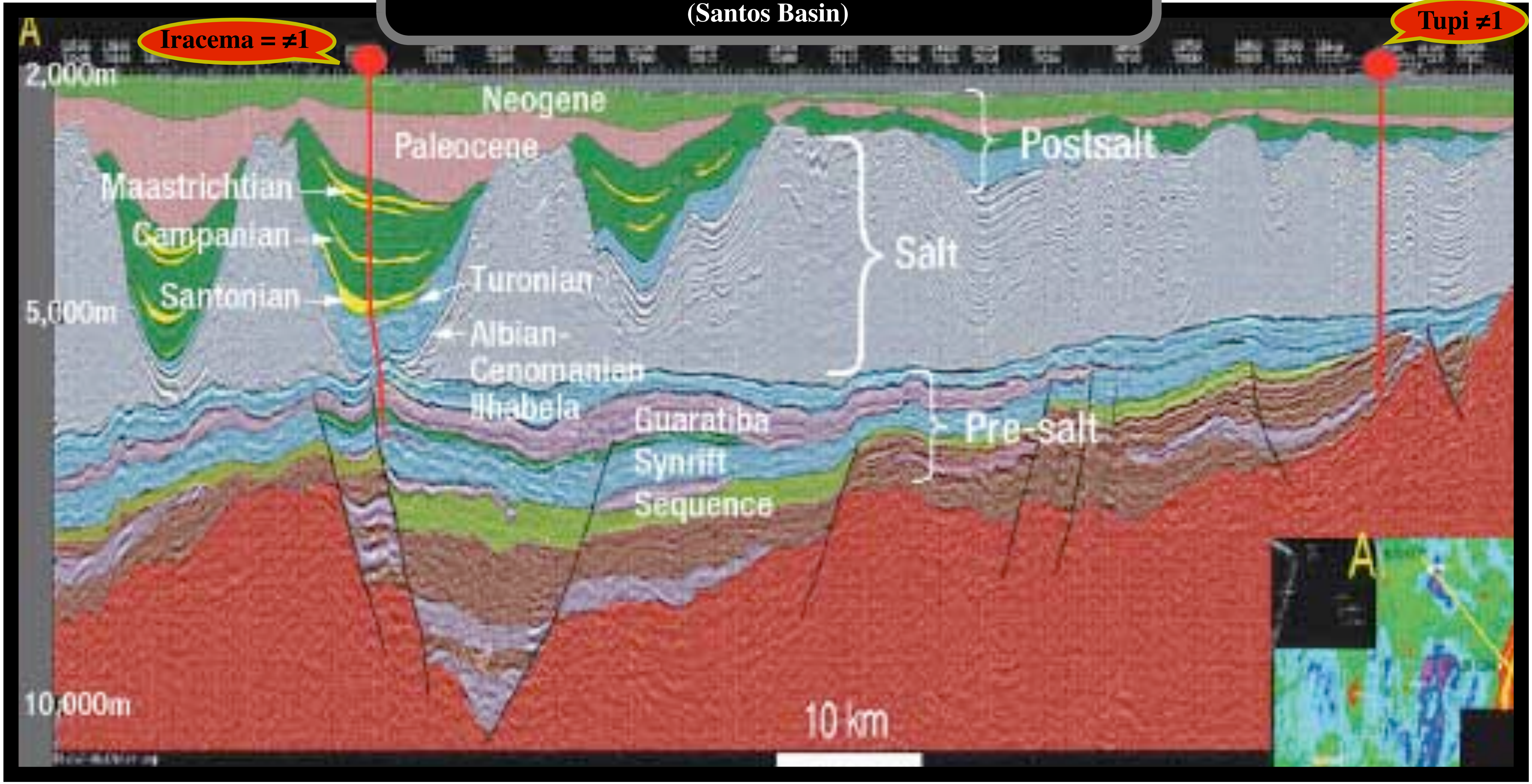
(Santos Basin)

- **The Tupi discovery lies beneath the Lower Cretaceous (Aptian) salt layer, which locally is more than 6,500 ft thick.**
- **Source and reservoir rocks are within a Lower Cretaceous (Barremian to Aptian) rift-type basin (Guaratiba Formation).**
- **Guaratiba source rocks are thought to be equivalent to the Lagoa Feia Shale source rocks of the adjacent Campos Basin.**
- **Reservoirs consist chiefly of lacustrine carbonates and associated coastal plain, fluvial and shallow marine clastic and carbonate.**
- **Traps are mainly morphological either in pre-rift or in the rift-type basin. The sealing rocks is the salt.**

Taking into account the distance between the Tupi wells and the nature of the reservoir-rock (lacustrine limestones), it is difficult to assume that the petrophysical characteristics of the reservoir will be similar all along of the trap, which type (structural or non-structural) and closure are difficult to hypothesize without all seismic lines and more appraisal wells. Carbonate reservoirs and particularly lacustrine limestone show often an high unpredictability.

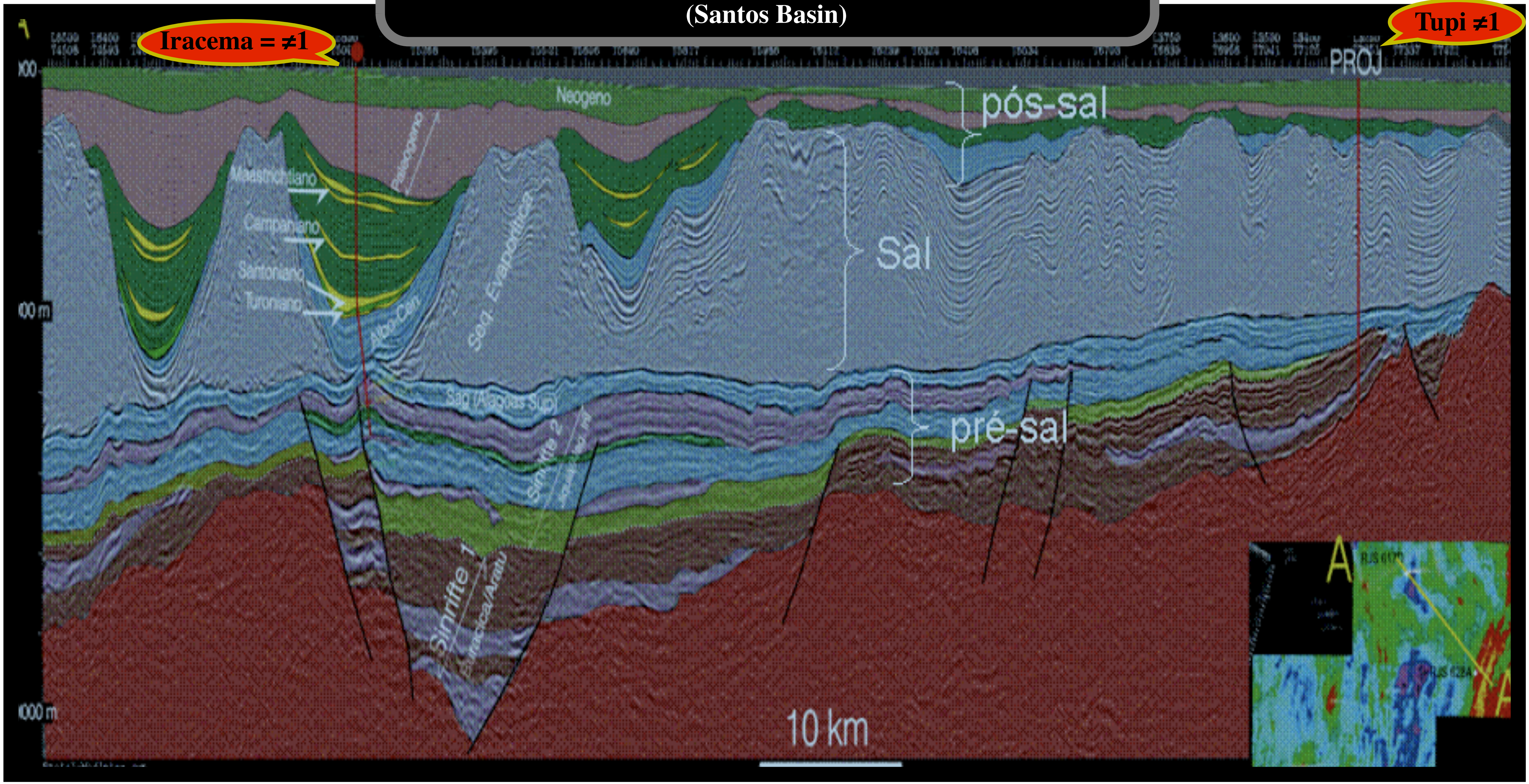
Regional Seismic Line

(Santos Basin)

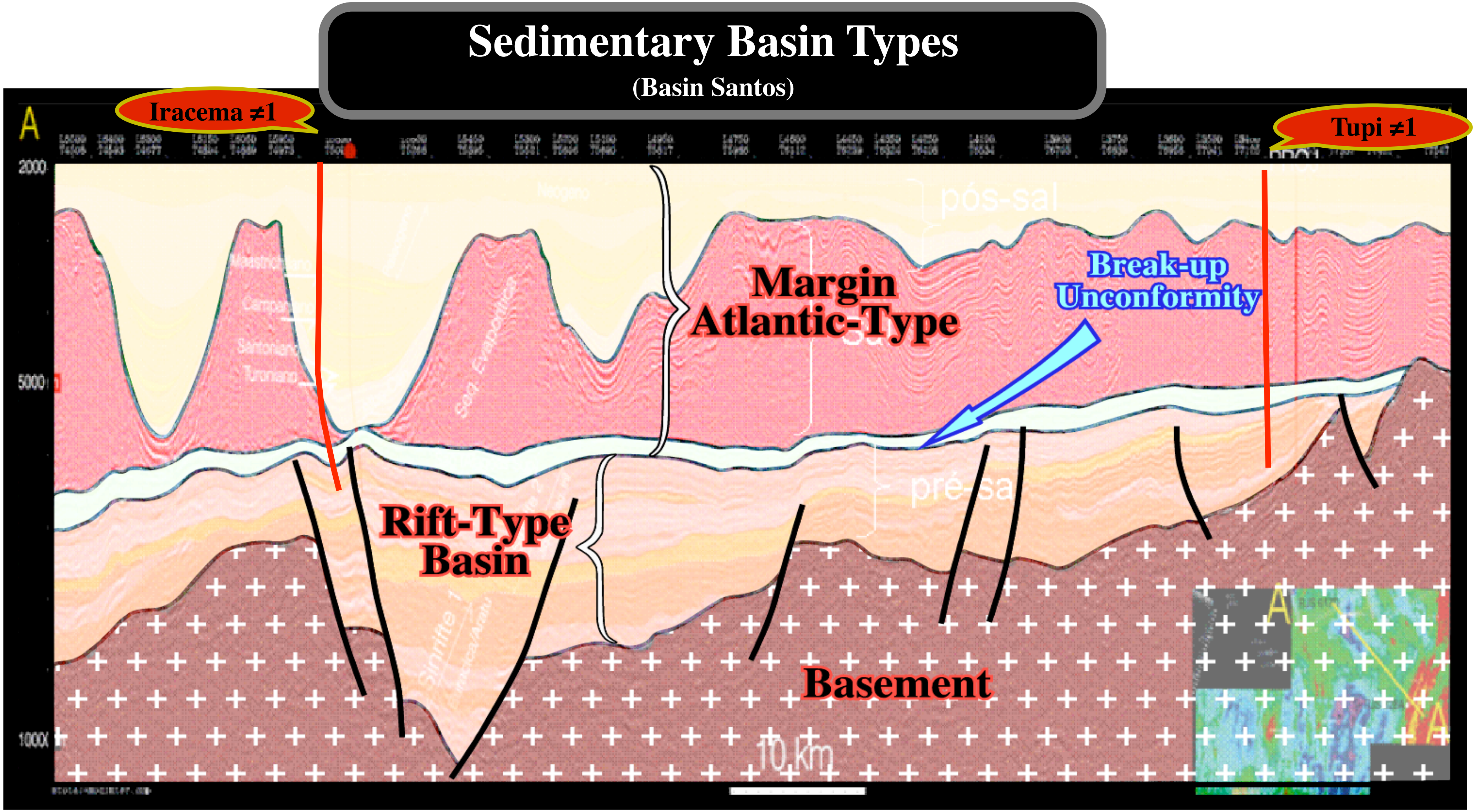


On this tentative interpretation, the author (a scientific journalist) followed the conventional post-salt, salt and pre-salt stratigraphic division of some brazilian geologists, that as we said previously can induce misunderstandings. In spite of that, the second hand author depicts a mixture of geological formations (compare with next plate), geological ages and tectonic phases (synrift sequence), that is to say that he has no idea what is going on in the sub-salt interval. However, the original published line by Petrobràs is much more clear and useful, as illustrated next.

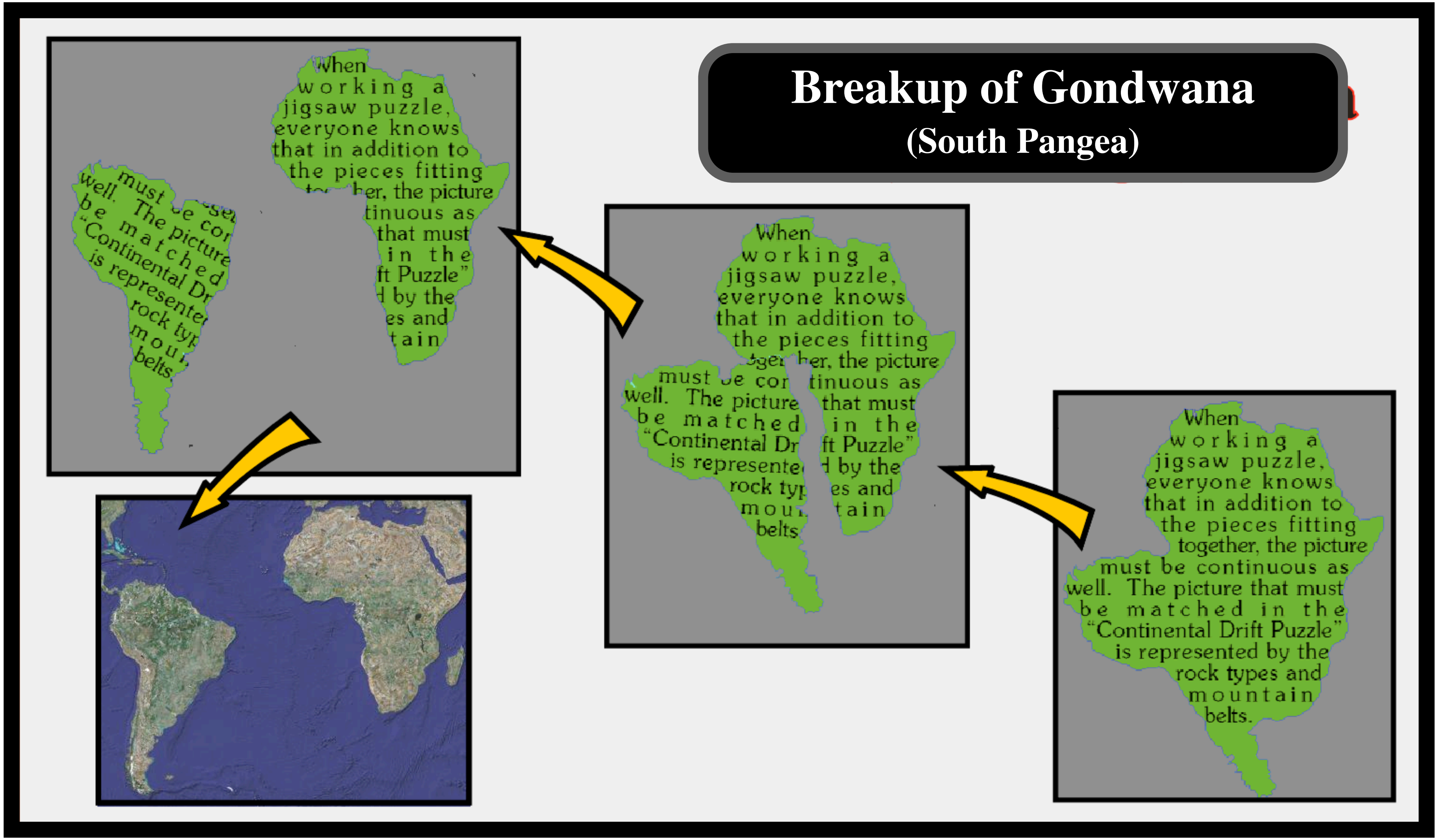
Regional Seismic Line
(Santos Basin)



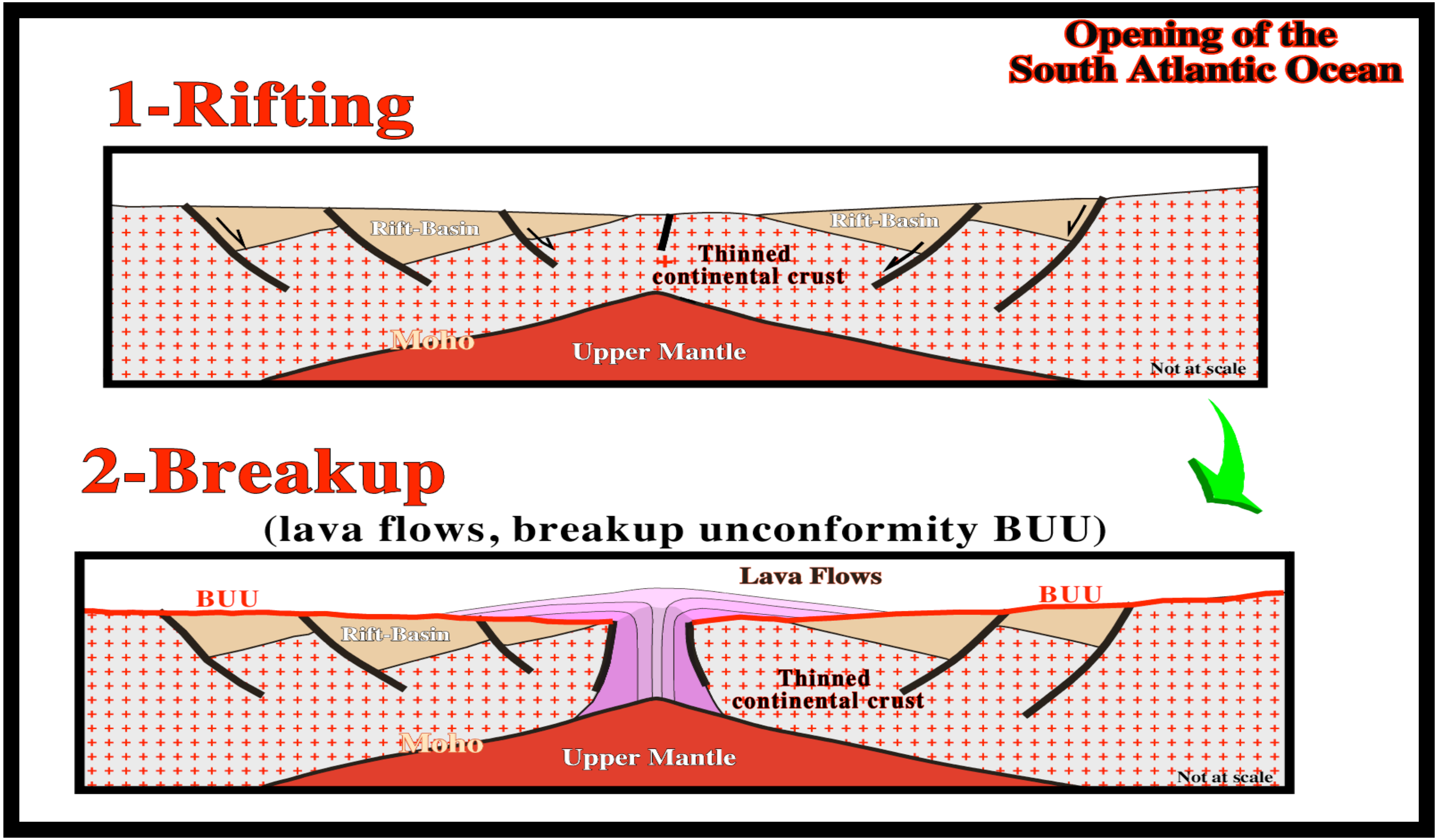
Here, the interpreter grouped the sub-salt sediments into two different basins: (i) rift-type basin sediments, where he recognized two different rifting phases ("synrift 1" and "synrift 2") individualized by a tectonically enhanced unconformity and (i) margin sub-salt sediments (sag) considered to form the Upper Alagoas formation. In other words, on this area without SDRs, the break-up unconformity corresponds to the limit between the sediments of the "synrift 2" and the sub-salt Upper Alagoas formation, which is supposed to correspond to the conventional Santos source-rocks.



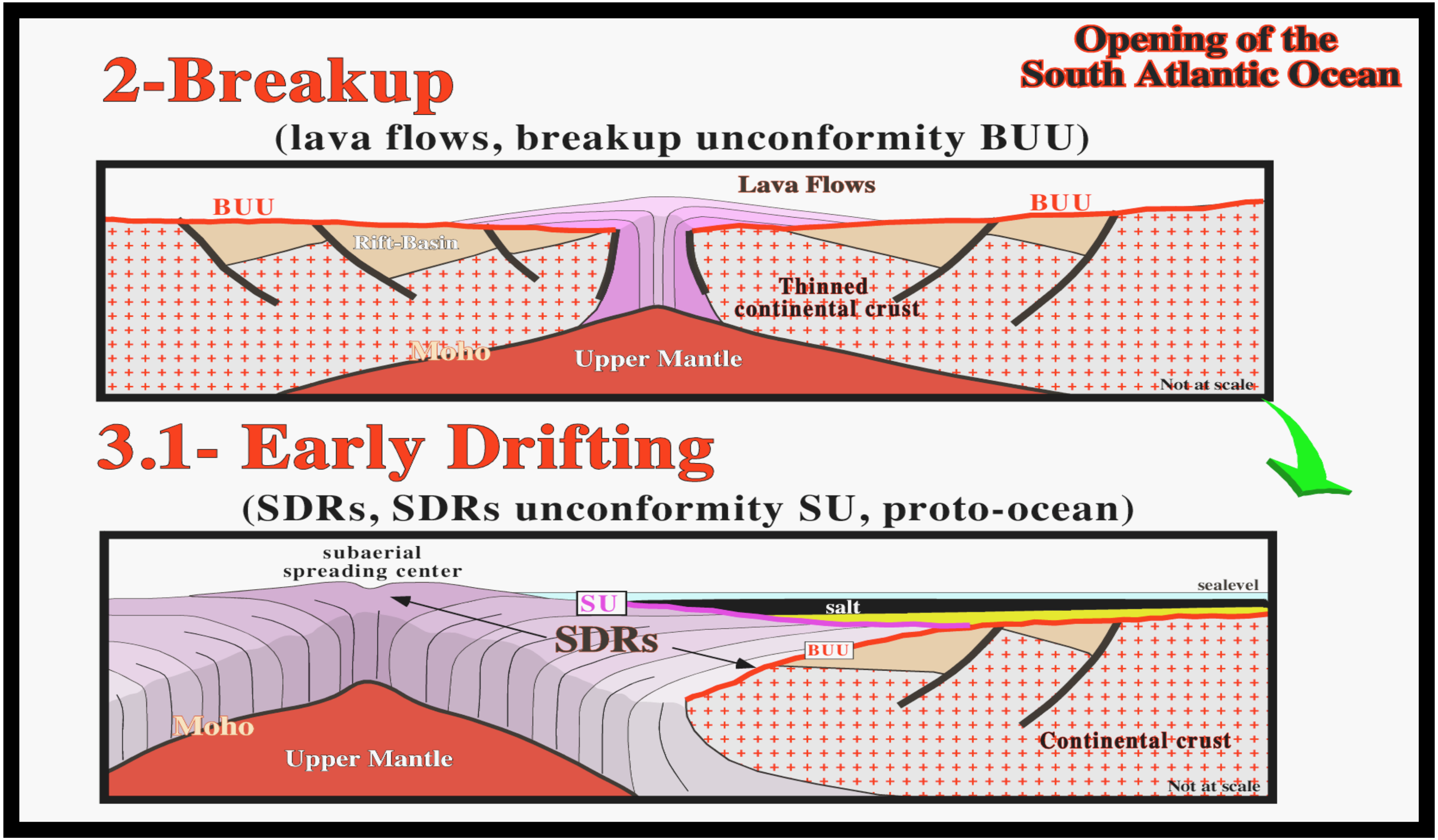
Using the realm of subsidence the major geological criterium, one can say that on the previous seismic line there are the superposition of three different basins: (i) a folded belt, which probably forms the petroleum basement, (ii) at least two rift-type basins and (iii) an Atlantic-type divergent margin, in which a sub-salt and a post salt interval are easily recognized. The breakup unconformity (BUU) corresponds to the top of the rift-type basins, while the tectonic disharmony fits with the top of the sub-salt sediments. The source rocks of Tupi discovery seem to associated with the sediments of the rift-type basins (as in Congo basin, Bucomazi source-rocks) rather than with the basal margin sub-salt sediments (sag sediments).



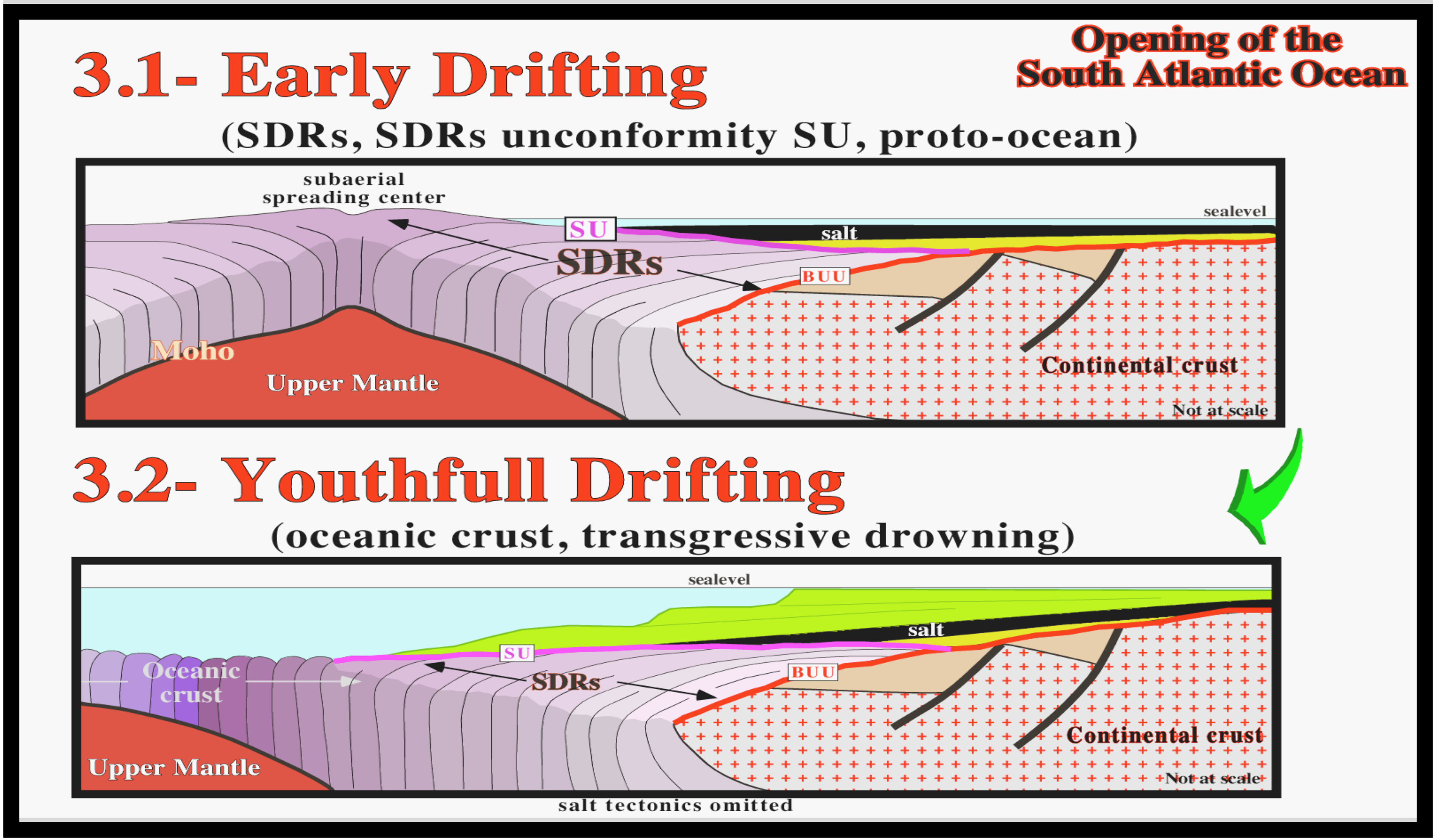
The understanding of the petroleum systems in which the generating and entrapment-migration petroleum subsystems are located in rift-type basins as well as the eventual correlation between Brazilian deep-water oil fields and Cabinda (onshore and offshore) fields requires, before all other things, the knowledge of the more recent hypothesis on the breakup of the Gondwana, since the old geological hypothesis, still followed by a lot of explorationists, have been systematically refuted not only by modern seismic data but well results as well.



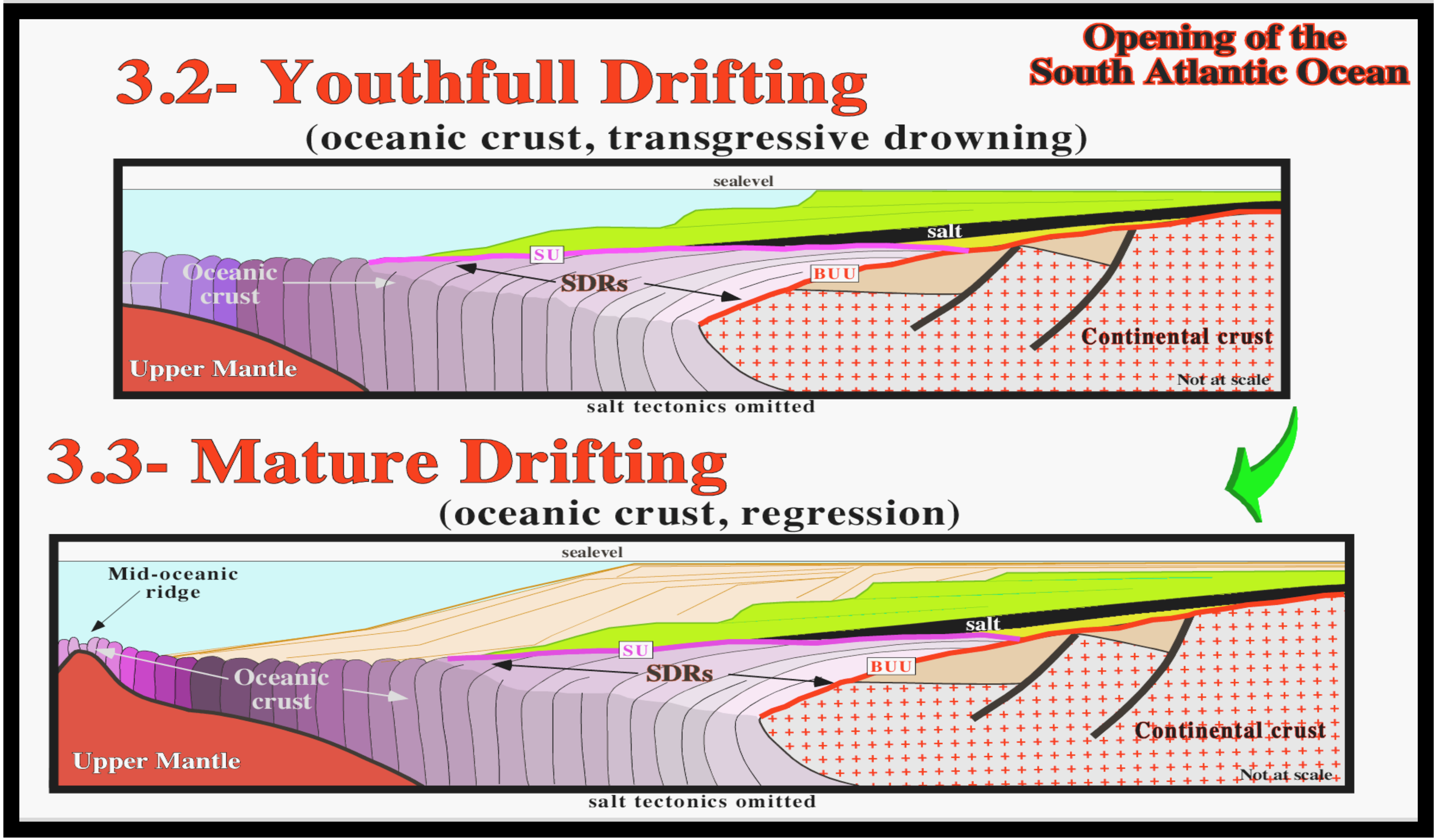
The less refutable hypothesis on the breakup of the Gondwana and development of the S. Atlantic continental divergent margins was proposed few years ago (2000) by Total's geologists. Such hypothesis can be summarized as follows: (i) Lengthening of the Gondwana lithosphere by normal faults with opposite vergences and creation of rift-type basins filled by non-marine sediments with thick interval of organic rich lacustrine shales (potential source-rocks, organic matter type I), (ii) When the thickness of the highly intruded lithosphere (central thermal anomaly) reaches 10-15 km, it cannot be lengthened anymore by normal faulting. It breaks by intrusion of volcanic material, starting the individualization of Africa and S. America plates.



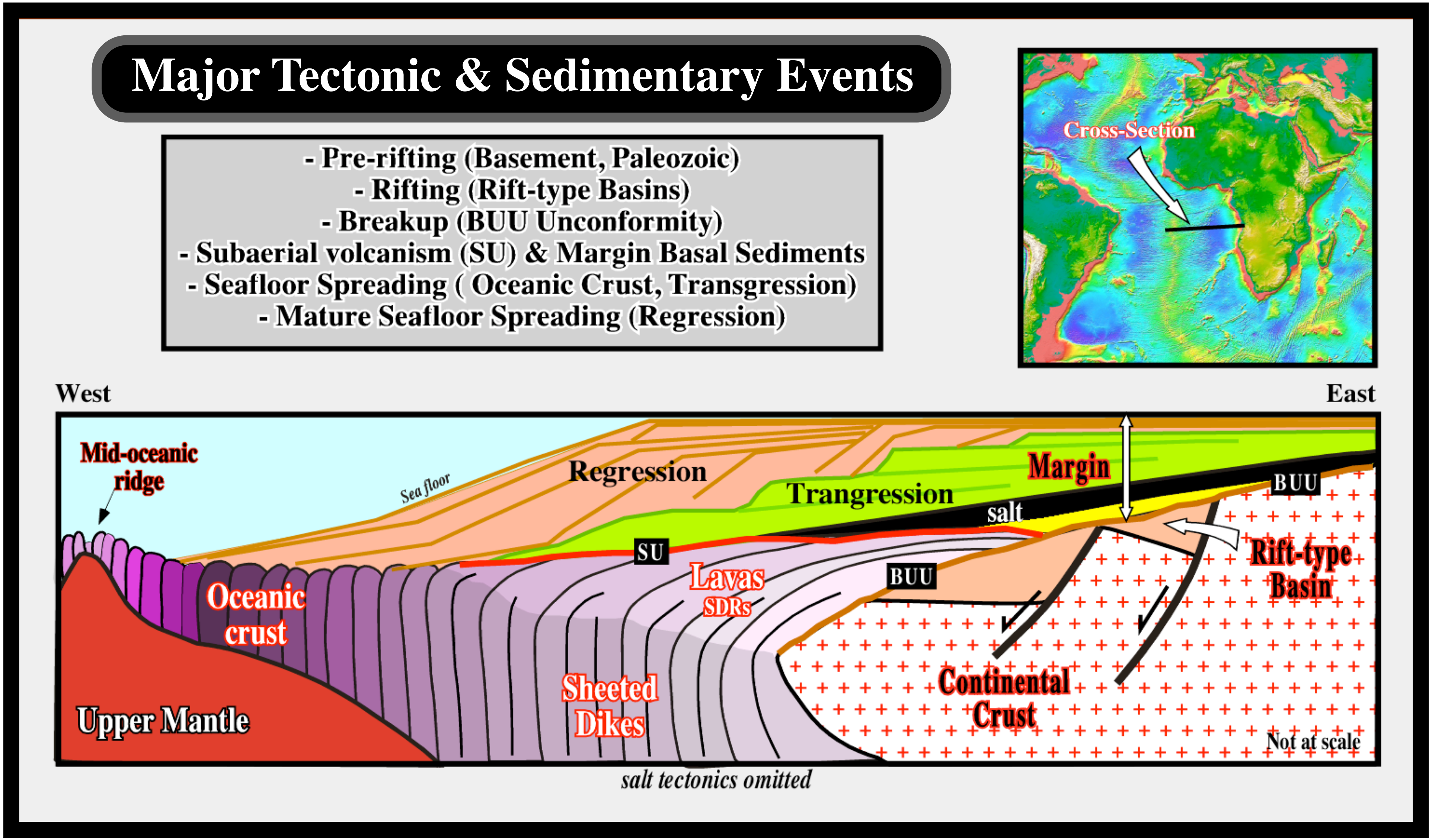
Since the lithosphere breaks, the volcanic material arriving into surface flows toward the new individualized continents forming a vertical stacking of sub-aerial lavas (subaerial volcanic crust) thinning away of the spreading centers. The continuation of this subaerial spreading increases the stacking of the lavas (over the sheeted dykes) allowing the development of a proto-ocean each side of the expansion center. Basal marine sandstones start to deposit, at same time that the reaction between the seawater and the lavas (spilitization of the basaltic material) strongly enhances the brine responsible of the salt deposition each side of the subaerial spreading center.



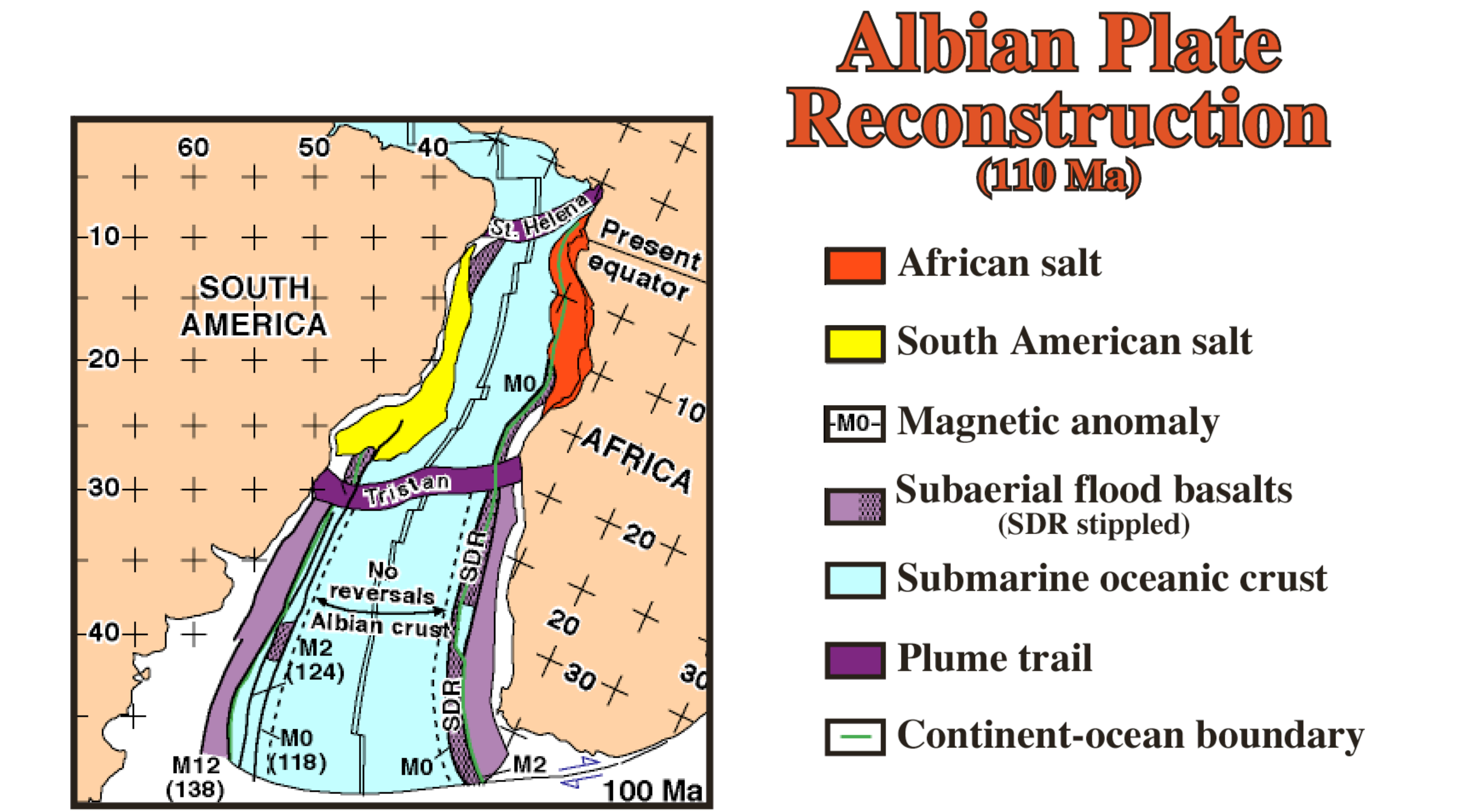
After a certain time, the loading of the successive lava flows is big enough to submerge the spreading center inducing the formation of a narrow (young) ocean by the connection of both proto-oceans. As the spreading center is under water, the volcanic material arriving to the bottom sea is frozen (it cannot flow) forming the oceanic crust (pillow lavas). Another consequence of the immersion of the spreading center and the continuation of the oceanic expansion (formation oceanic ridges) is the volume reduction of the oceanic basins what, for a constant volume of water, creates an eustatic rise (global rising) with which the transgressive phase of the post-Pangea continental encroachment cycle is associated.



The eustatic rise is the responsible for the deposition of the transgressive sediments over the salt layer in both margins (W. Africa and S. America). These sediments display a characteristic backstepping geometry. When the post-Pangea eustatic high is reached (Cenomanian-Turonian), the eustatic sea level falls due to the increasing volume of the oceanic basins (induced by the continental collisions and subduction of oceanic material). The consequence of such eustatic sea level fall is the deposition of a forestepping interval, i.e., progradational interval, which fossilizes the maximum flooding surface (MFS 91.5 Ma, i.e. the flooding surface that occurred 91.5 million years ago).

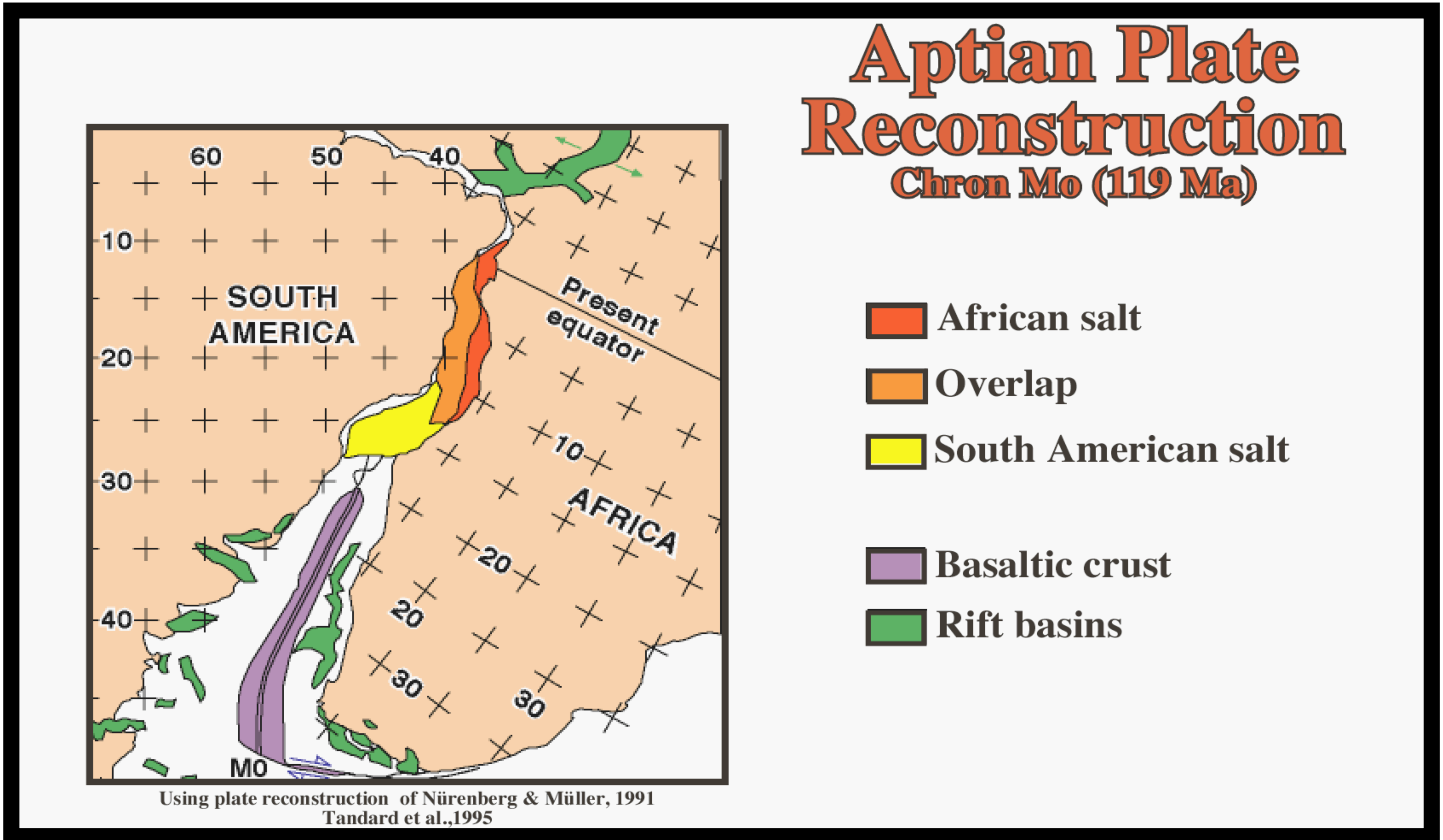


This cross-section of the offshore Angola illustrates the main geological features allowing to understand the different petroleum systems (i) The upper limit of the rift-type basins is the break up unconformity (BUU), (ii) The BUU is fossilized by the SDRs (subaerial volcanism) or by the margin sub-salt sediments, (iii) The SDRs have no generating hydrocarbon potential (5 m of lacustrine shales are known in Austral basin), (iv) The Angola-Congo and Brazilian salt basins are twined basins, i.e, they have always been individualized, (v) Potential marine source-rocks are likely in the transgressive interval of the margin and (vi) Potential dispersive source rocks (organic matter type III) are possible in the regressive interval.

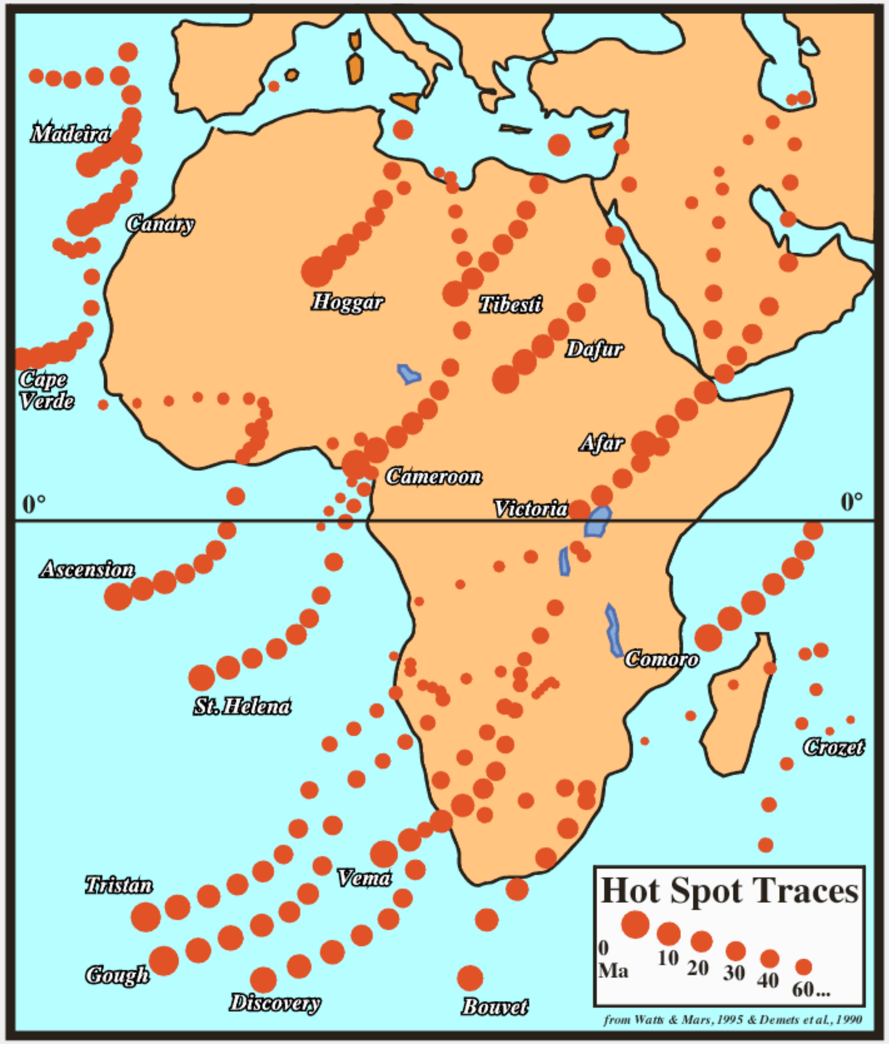


Using plate reconstruction of Nürenberg & Müller, 1991

During more than 50 years explorationists were convinced that the original salt basin (the Brazilian-Angolan salt basin), was splited in two salt basins by the breakup of the Gondwana. This conjecture implied that (i) The breakup postdated the salt and (ii) All sub-salt source-rocks were located in rift-type basins. All new geological and seismic data have been refuting such hypothesis. The argument that the thickness of salt is higher in deep-water because it marks the center of the original salt basin, often used as ultimate argument, is falsified by the new seismic data, which strongly suggests that the large thickness of the salt, in deep-water, is due to a shortening of an allochthonous salt layer in response to the up-dip lengthening. In the sense sense, the pre-stack depth migrated seismic lines of deep-water Angola readily indicated the western border of the eastern salt basin.



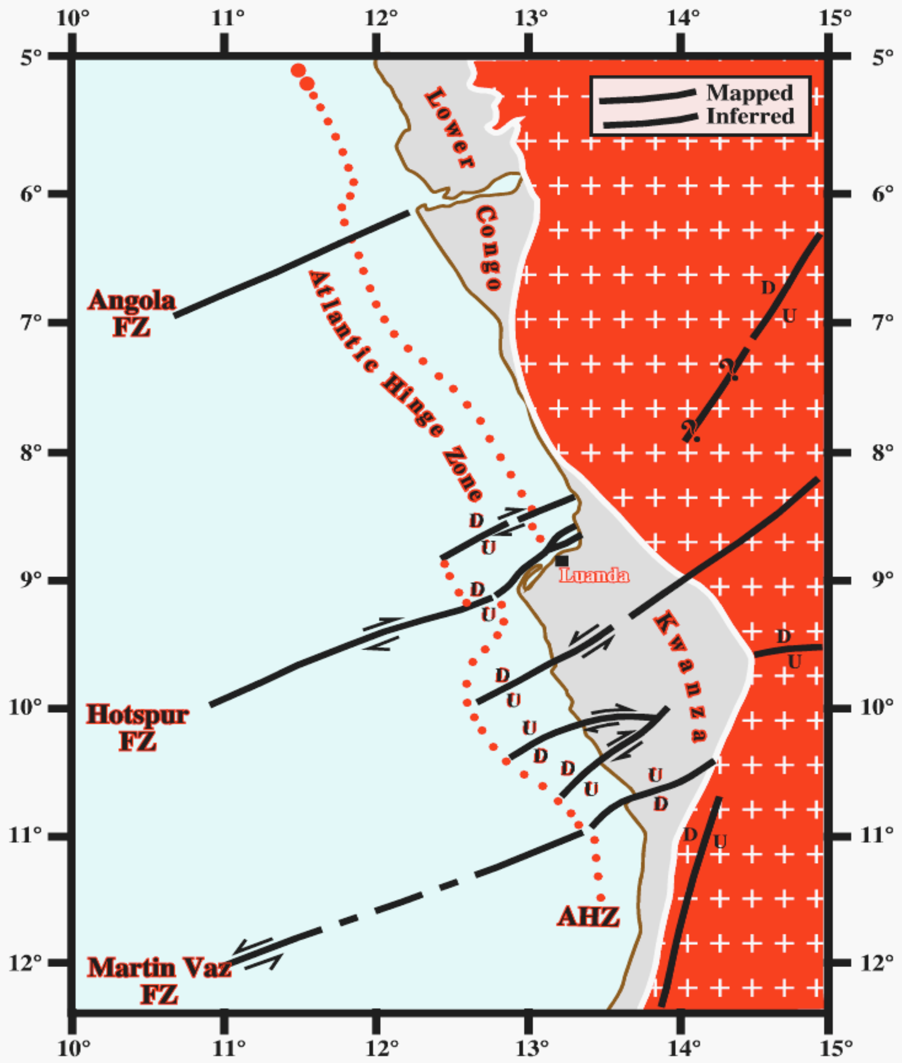
On the other hand, the palinspatic reconstruction strongly suggest two twin salt basins, each side of the subaerial spreading center and perfectly individualized. Indeed, taking into account the age of the salt and the magnetic anomalies, all geological reconstructions show an overlap of the South America Salt and the African salt basin at the time of the breakup, which refutes, or falsify, the hypotheses of an unique salt basin. Again, the margin sub-salt sediments and the potential sub-salt source-rocks, can belong to two completely different basins: (i) Rift-type basins, as the lacustrine (organic matter type I) and (ii) Divergent margin (sub-salt hyper-saline, in Brazil, or sub-salt Falcão-type, in block 6 of offshore Angola).



Relative African Plate Motion to Hot Spot Trails

(trails at 10 My intervals)

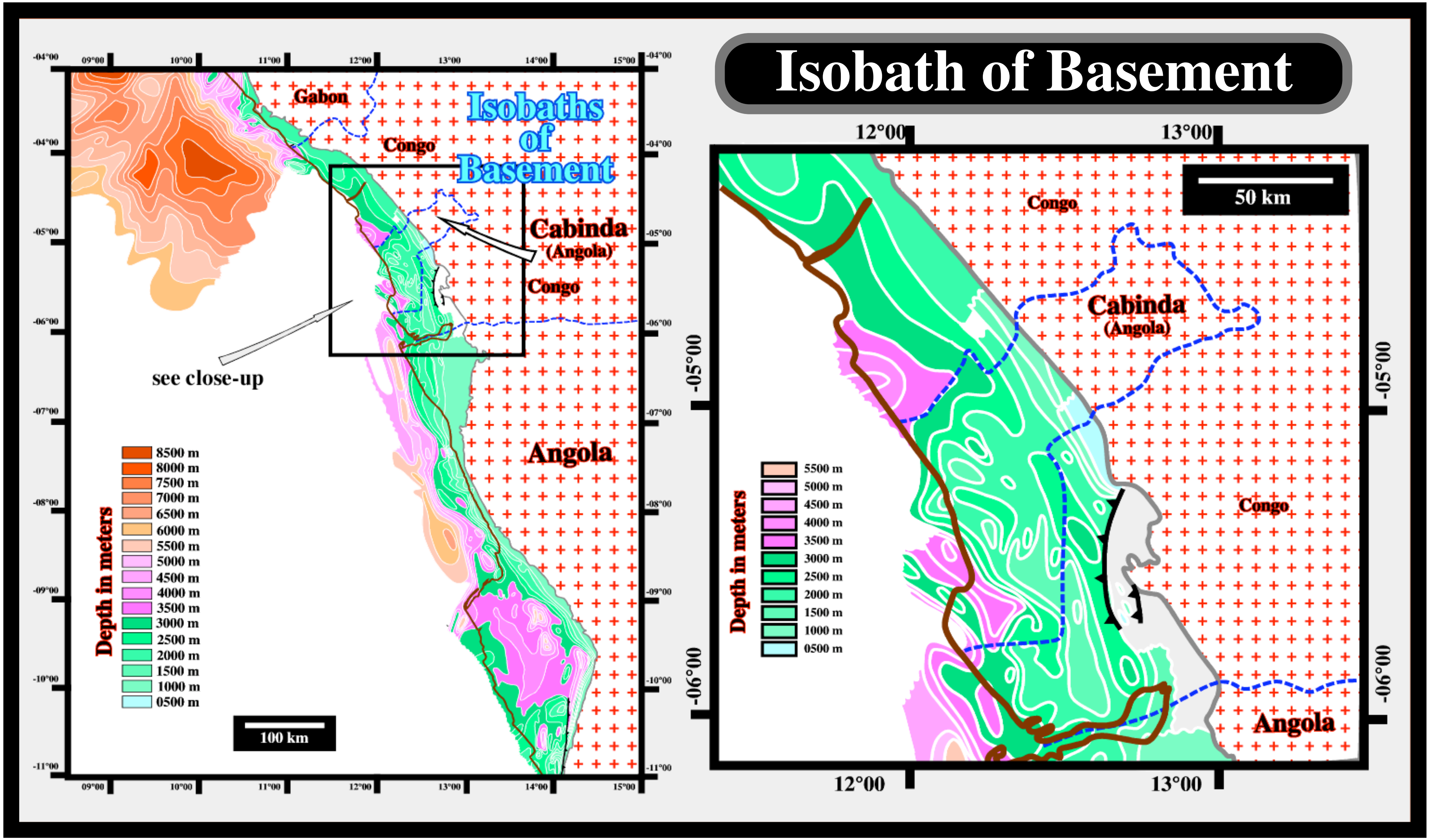
Taking into account the previous conjectures, it is quite evident that the major step to understand the location of the different petroleum systems (rift-type and margin systems) is to draw the more likely limit between the continental crust, where rift type-basins are possible, and the volcanic crust, i.e the subaerial lavas flows, which postdate the breakup. The rift-type source-rocks are just possible below the distal lava flows, under which distal rift-type basins are possible (near the breakup fracture). The COB (continental oceanic boundary), in fact, correspond to the limit between the continental crust and the lavas flows (subdue magnetic anomalies- horizontal geometry) rather than the oceanic crust (sheeted dykes, sharp magnetic anomalies).



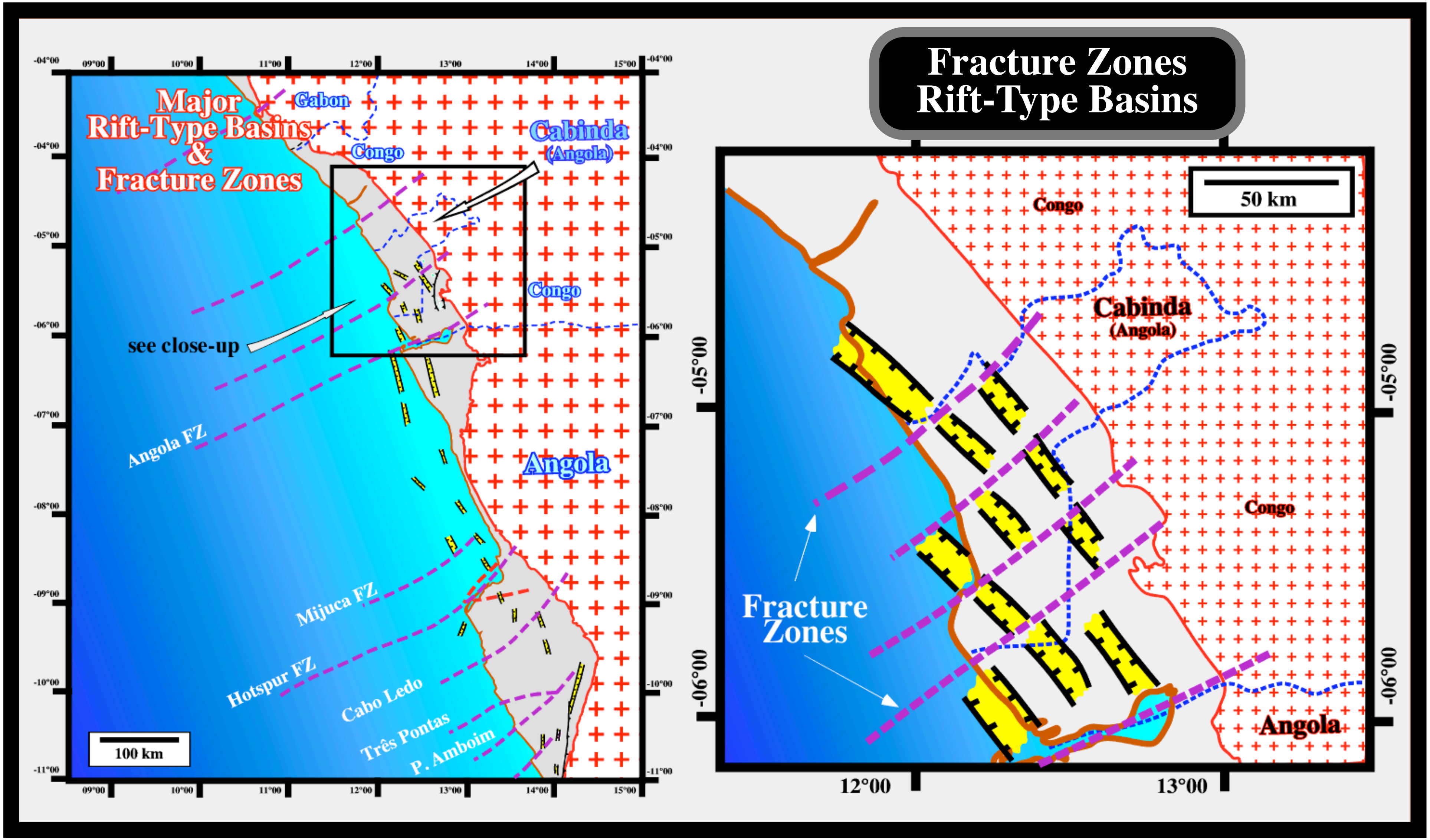
Major Fracture Zones

The major fractures zones in the Kwanza and Congo basins, as well as the Atlantic Hinge Zone are illustrated on this map. In Luanda offshore, the exact position of the Atlantic hinge zone is controversial. Such a geological feature recognized by Brinks, on onshore Gabon, has been extended on offshore Congo and Kwanza. Assuming the mapped feature is the same, the Atlantic hinge zone corresponds to a step of the bottom of salt. Such a step was probably induced by an upward movement. Erosion is bigger when the step is present. Its age is controversial. The more likely seems to be mid-Miocene, since stratigraphy is strongly affected. Other ages have been proposed, such as Aptian or older. The proposed ages depend how the steps of the bottom of the salt is explained.

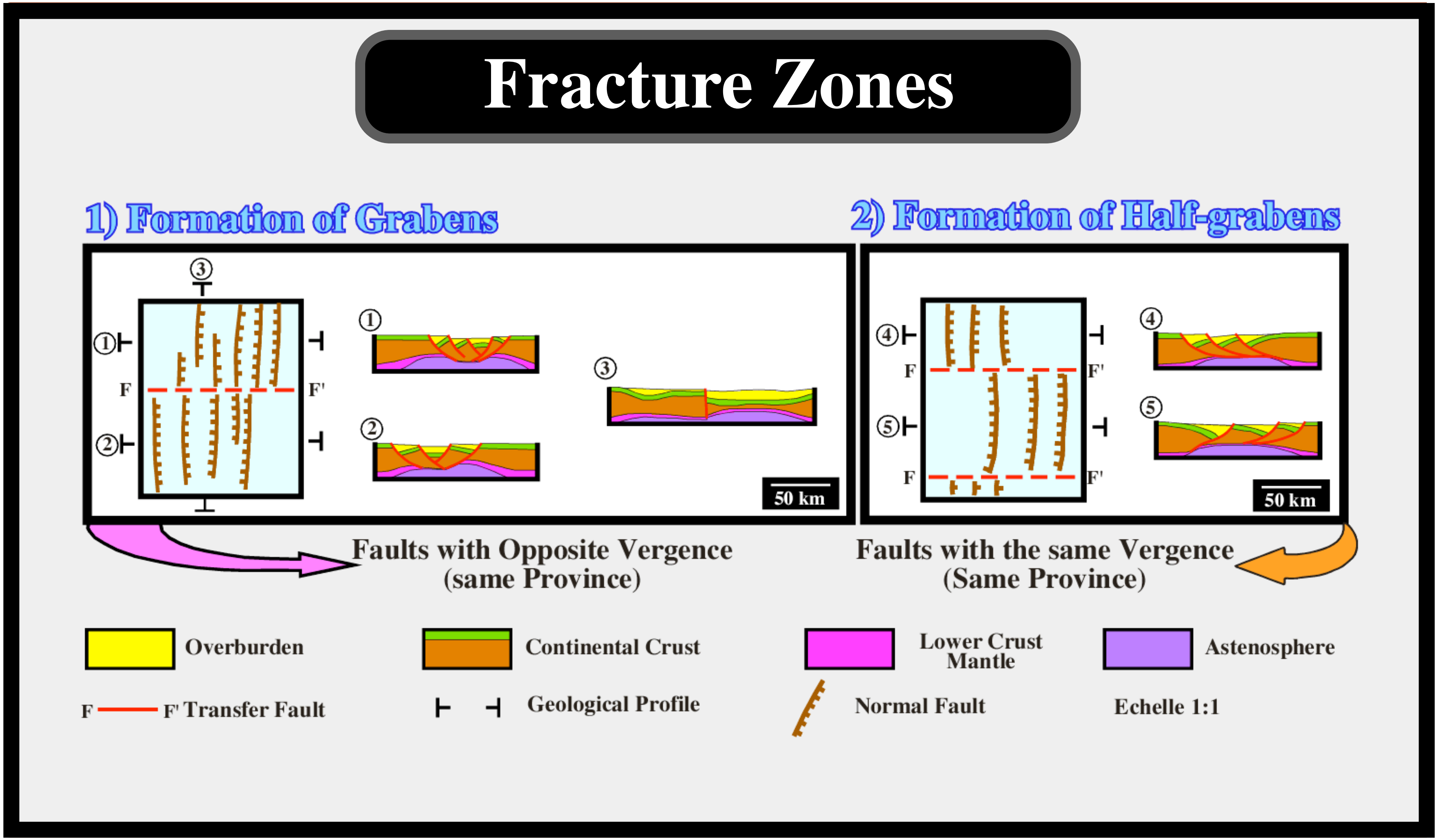
The limit between the continental crustal and the volcanic crust (SDRs) is apparently displaced laterally by extensional strike-slips (fracture zones), which follow roughly the direction of the hotspot trails illustrated in the previous plate. The major fracture zones, as Hotspur, Mijuca, Martin Vaz and others are known of all geologists working in the interested area. However, the mapping of secondary order fracture zones, which have a major impact in the location of the non-stratigraphic traps particularly in deep-water requires an exhaustive sequential interpretation of the modern seismic data.



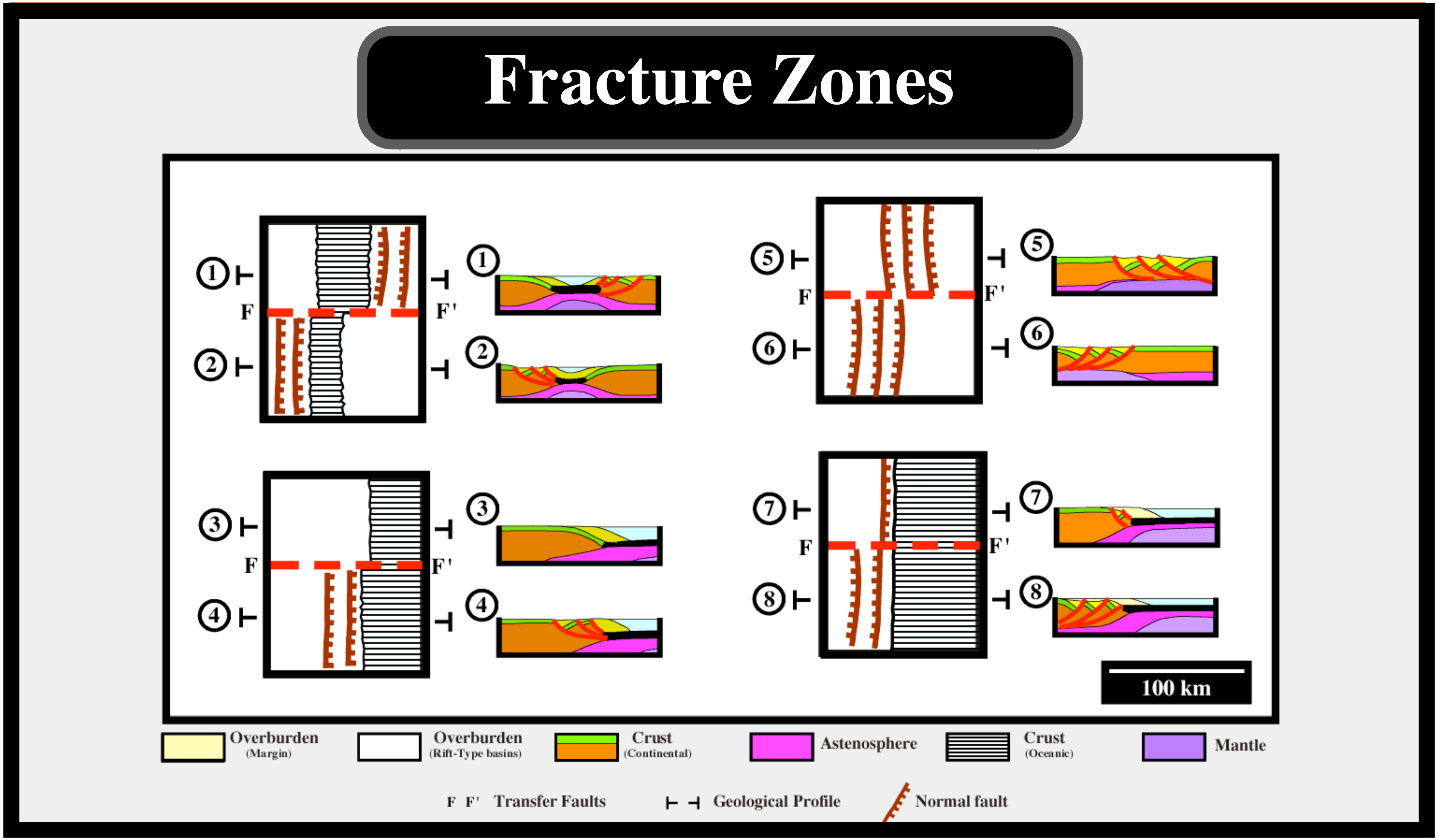
On this regional map of the basement of the Congo and Kwanza basins is quite easy to recognize the major extensional strike slip faults (fracture zones), which individualize different rift-type basins, and so, the more likely location of the potential lacustrine source-rocks, i.e., where the Bucomazi formation is likely (Congo basin). In Kwanza basin (southward of the Ambriz basement promontory in the regional map), the size of the rift-type basins and the rate of extension are inadequate to develop lacustrine rocks. When the rate of extension is balanced by the terrigeneous influx (lateral terrigeneous influx too high due to small width of the rift-type basins,) the infilling is mainly sand-prone and the development of source-rocks unlikely.



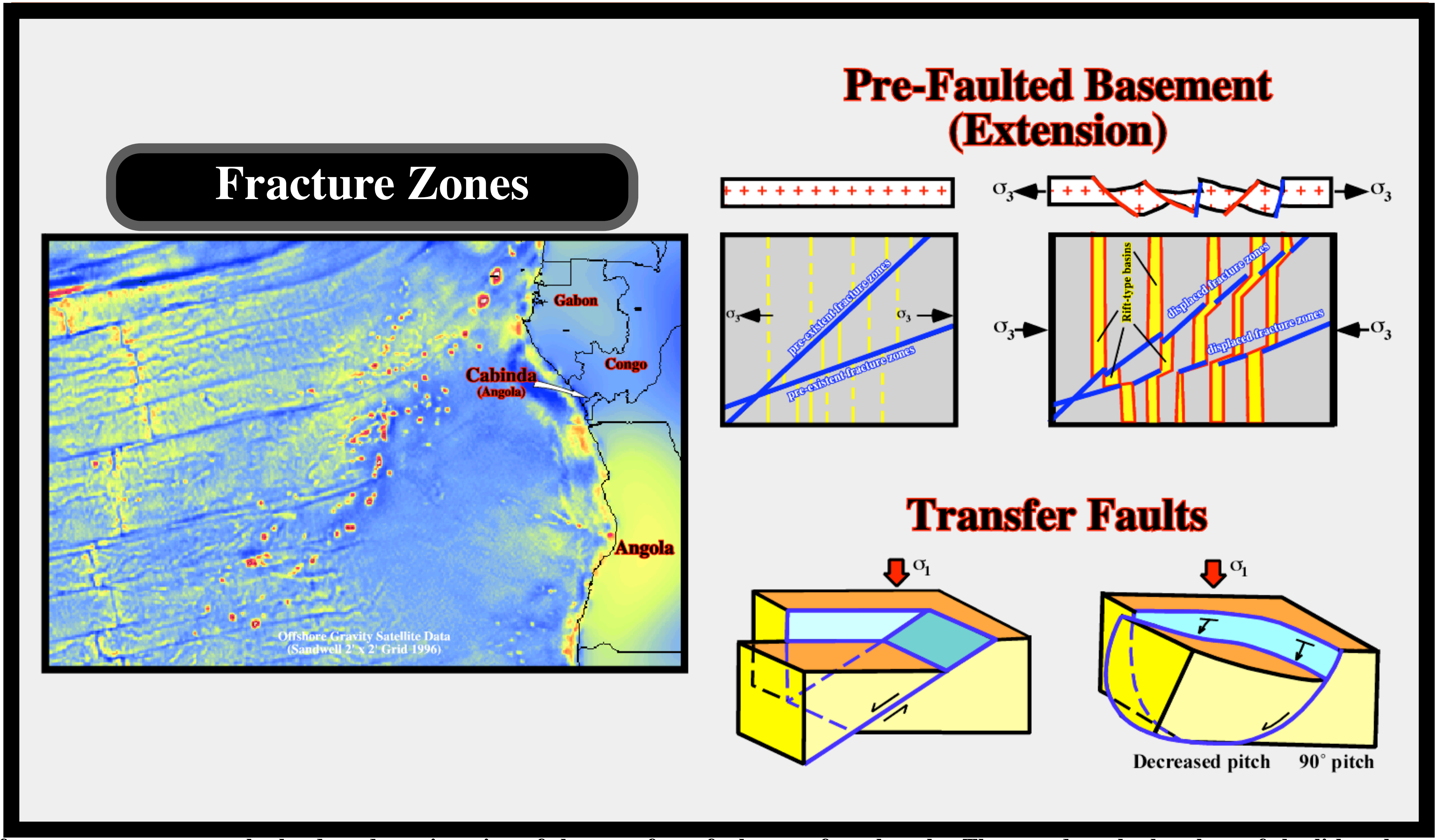
Using the results of the wells drilled, in the 60' s, by Gulf Oil without seismic data and the tentative interpretation of the lines shot in 1972, the major fracture zones in the onshore and conventional offshore of Cabinda are easy to identify as the rift-type basins. The identification of the rift-type basins is a key parameter to located the generating petroleum subsystem, i.e, the Bucomazi formation. The fracture zones correspond to extensional strike slip faults. The rift-type basins are not displaced and are not correlationable each side of the fracture zones. Two consecutive fractures zones define a geological and petroleum province. Adjacent rift-type basins can have completely different in-fillings and petroleum potential.



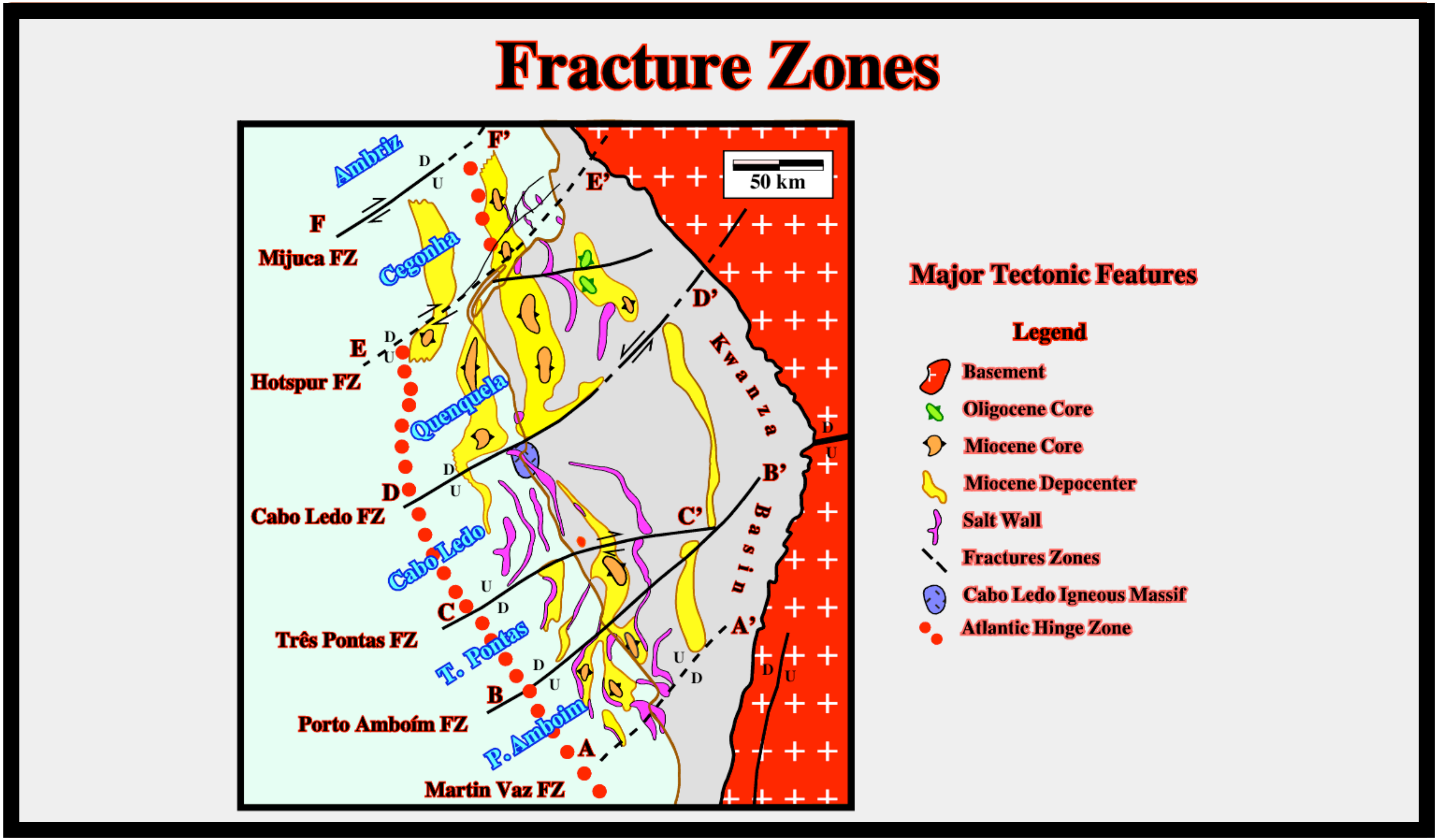
These fracture zone sketches, taken from A. Bally, a quite useful to recognize them on seismic data, particularly when the seismic lines are located in different geological province (defined between two consecutive significant fracture zones). On the left, the geometry of the rift-type basins on the seismic lines of different provinces is similar, but the strike line allows easily to recognize the location of a fracture zone. On the right, the normal faults associated with the rift-type basins of different provinces have a different vergences. The more likely location of the fracture zone correspond to the change in vergence of the normal faults.



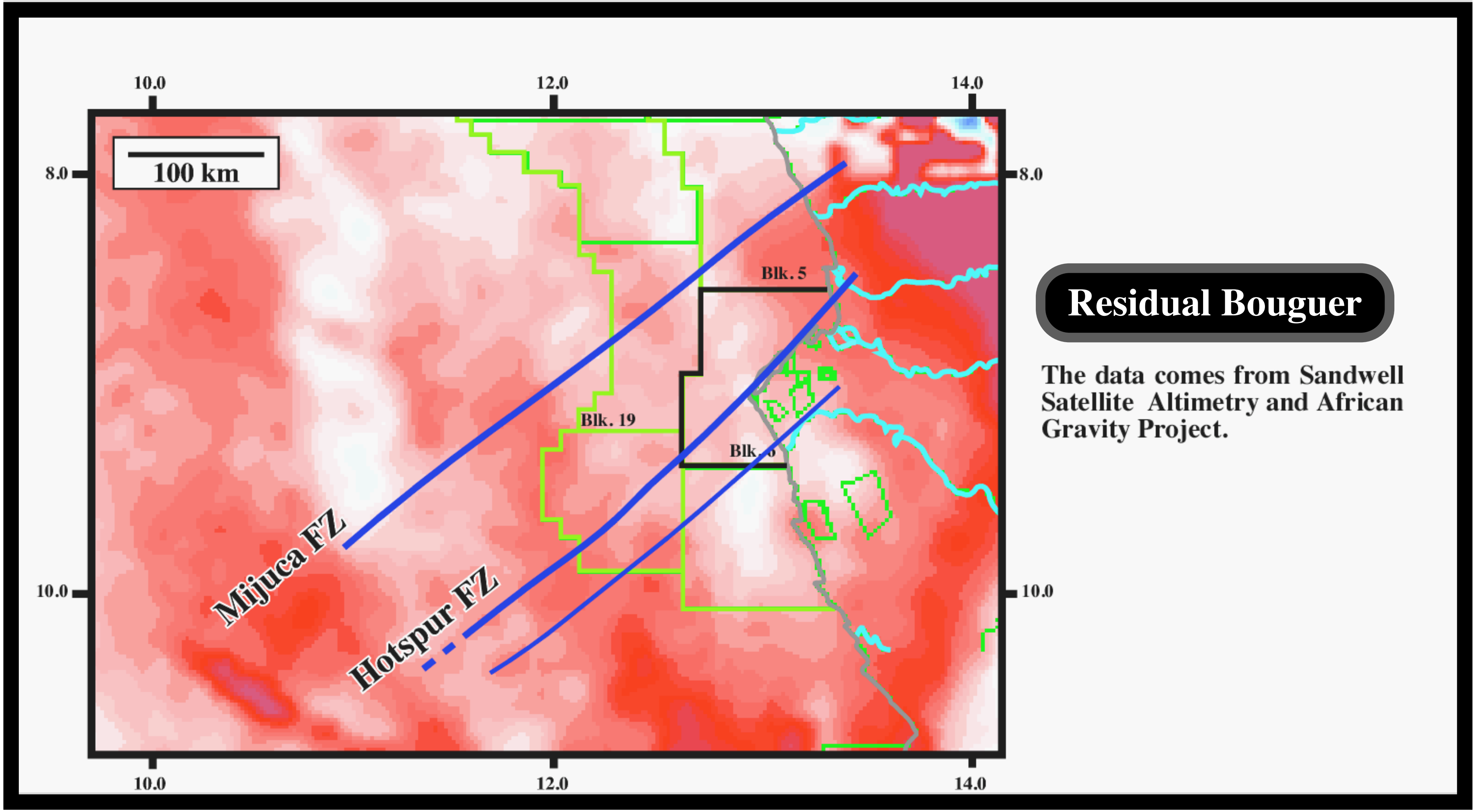
On this sketches with oceanization (post breakup sediments) the location of the fracture zones follows the same principles that previously. On the left, the opposite vergence of the normal faults associated with the rifting can be a criterium, as well as the abrupt disappearance of a rift-type basin. On the right and above, the opposite vergence of the normal faults affecting the continental crust, as below with oceanization, allow a readily location of the fracture zone. Admittedly, the geometry of the pre-breakup sediments allows much better the location of the fracture zones than the geometry of the margin sediments. Structural traps are likely along the fracture zones, particularly when these are reactivated by oceanic-ridge pushing.



The fracture zones are not the landward continuation of the transform faults, as often thought. They predate the breakup of the lithosphere. They correspond to weak zones of the lithosphere, which favor the pristine breakup fracture. The original breakup fracture is homogenous and continuous within each geological province bounded by major fracture zones. The mid-oceanic ridges are apparently displaced at each major fracture zone (in the left). The extension of a pre-faulting basement works in a similar way (in the right). The rift-type basins are not displaced by strike-slip faults. They are unique, within each geological province. They strike parallel to the medium effective stress (σ_2) of the tectonic regime responsible for the extension. In certain conditions, secondary "rift-type basins" can develop along the pre-break-up fracture zones.

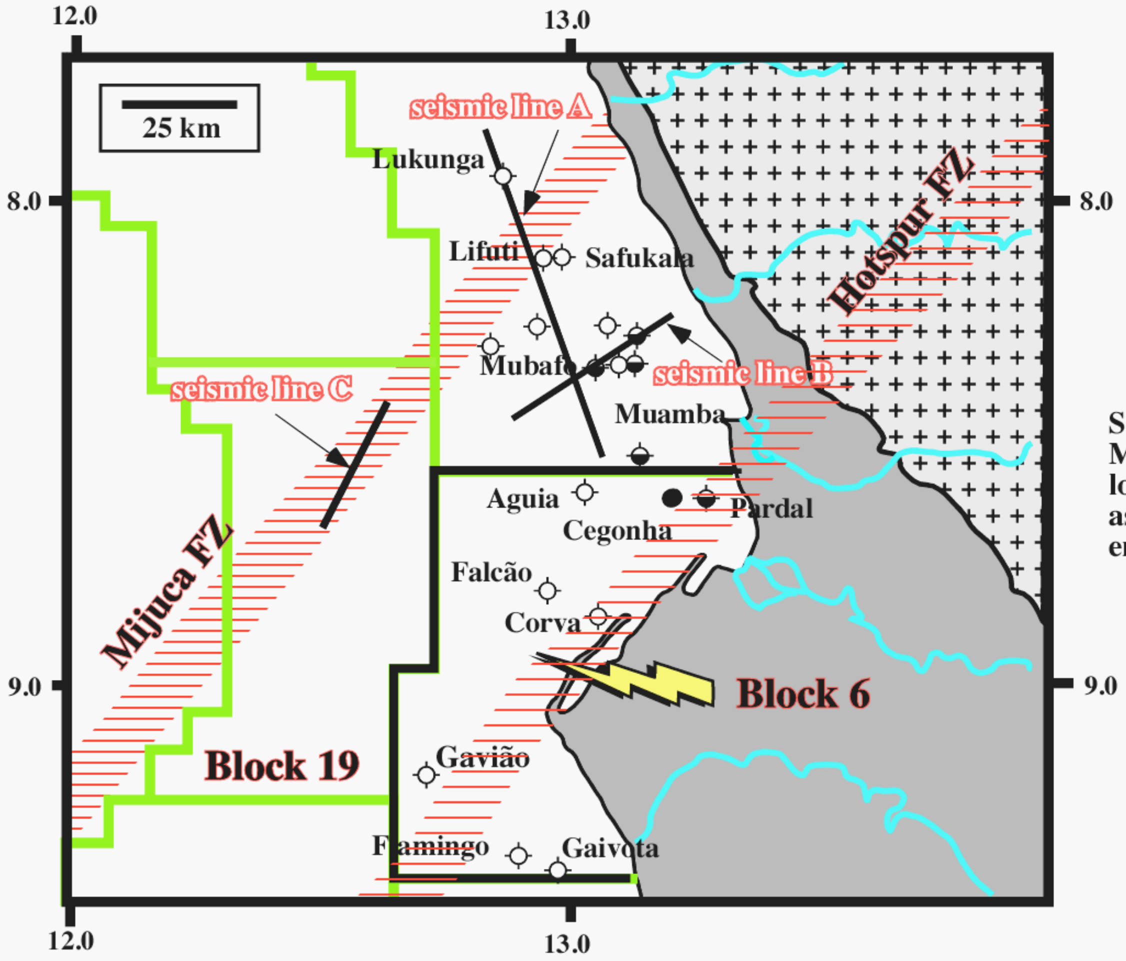


In onshore Kwanza, the major fracture zones are well known. They individualize geological provinces with different petroleum systems. Within each geological province, the tectonic disharmony, induced by salt tectonics, has a typical seaward dipping and typical Miocene depocenters. The reactivation of the fracture zones by "oceanic ridge pushing" creates compressional structures along the strike of the fractures. All these fractures are also recognized in offshore Kwanza and in Congo Basin. The Atlantic hinge zone does not correspond to the limit between the continental and volcanic crust but rather to the hinge of the seaward tilting of the basin, which is enhanced by the Late Tertiary uplift of the onshore border of the margin.



The residual Bouguer, in conjunction with seismic and geological data, can be used to map the major fracture zones of a divergent margin, as illustrated here by the plot of Mijuca and Hotspur fractures (northern Kwanza basin, Angola). The interesting point is that, generally, an exploration block is cut by one or several fracture zones. Subsequently, different geological provinces and petroleum systems (with different potential) can be often recognized. If that is so, the first step to evaluate an exploration block in South Atlantic offshores, is: (i) To map the major fracture zones, (ii) To pick the more likely limit between the continental crust (rift- type basins possible) and the volcanic subaerial crust (no rift-type basins). Let’s see an example.

Fracture Zones
(Seismic Lines)

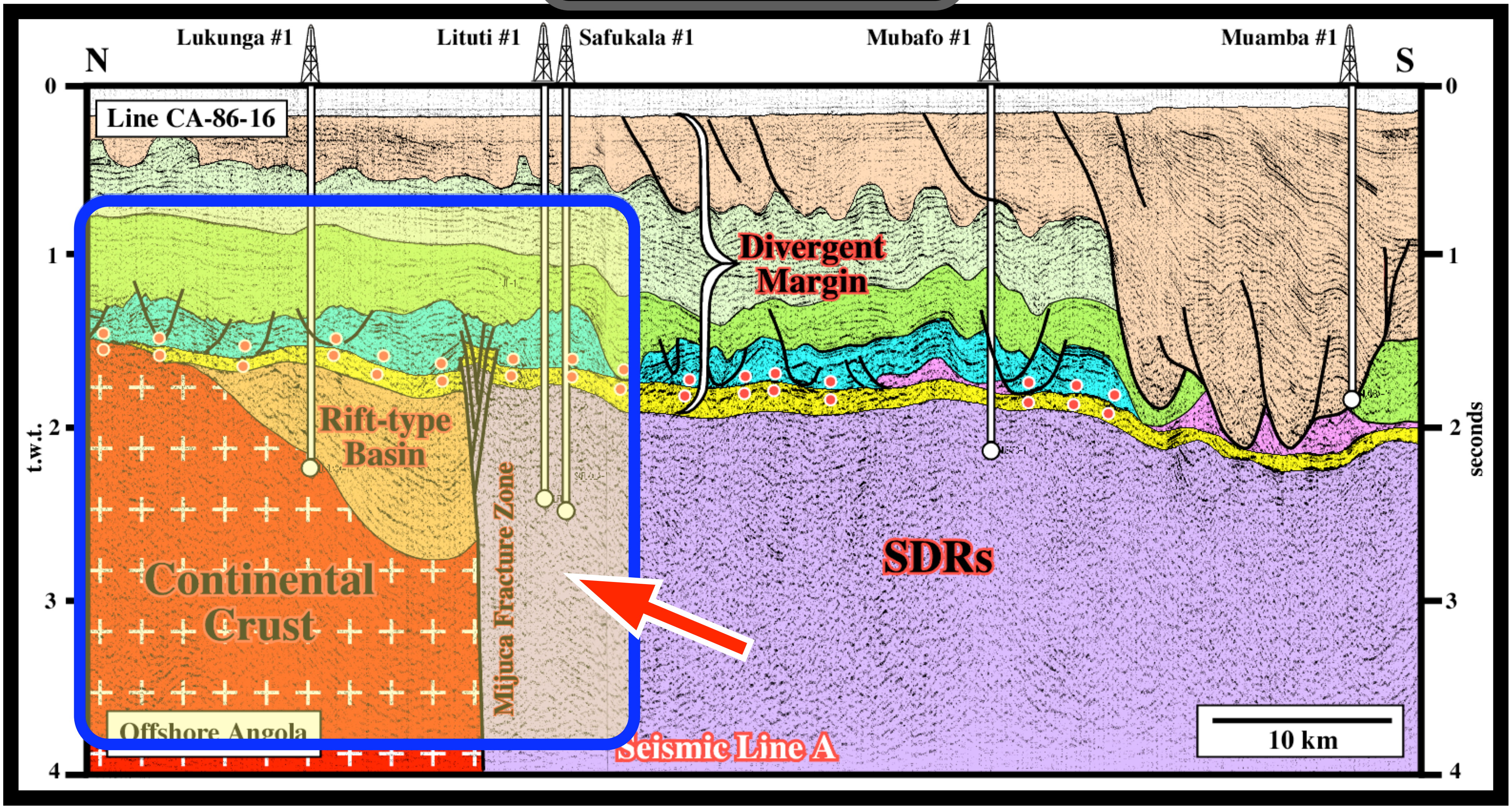


Location Map

Show on this map are the traces of Mijuca and Hotspur fractures zones, the location of the key seismic lines, as well as the wells drilled on block 6 and southern part of block 5.

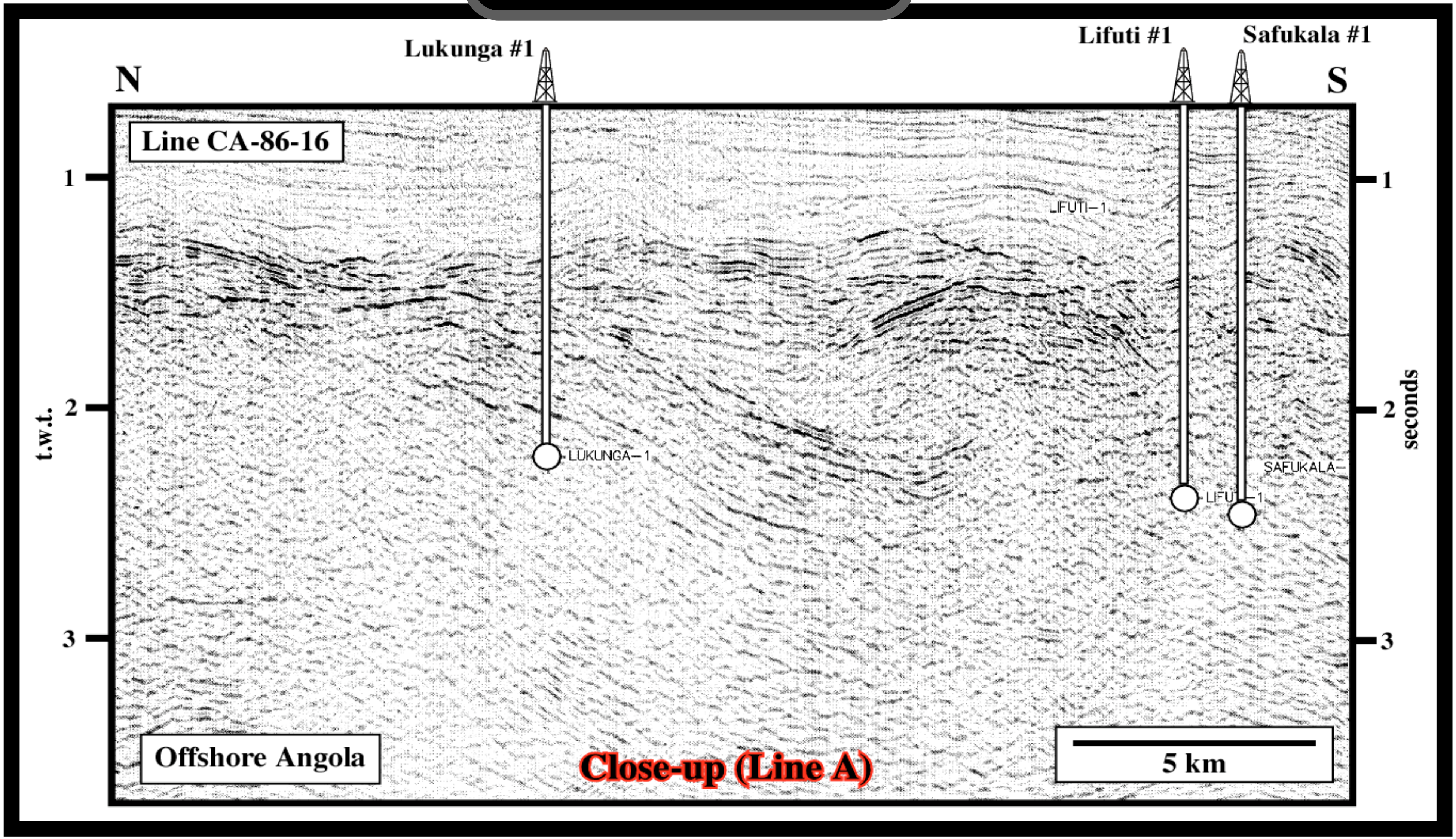
In the northern offshore of the Kwanza basin, the exploration blocks 19, 6 and 5 are cut by the Mijuca and Hotspur FZs. Each block is composed by different geological provinces with probably different petroleum systems. The Mijuca fracture zone is corroborated by the seismic lines A and C. The seismic line B is, apparently located in a single geological province, in which several wildcat indicate the presence of hydrocarbons. The wildcats drilled in block 6 and block 5 tested different geological provinces, as for instance Lukunga ≠1 and Safukala ≠1. Before trying to map the limit between the continental and the volcanic (sub-aerial) crust, let's take a look at the seismic lines.

Seismic Line A

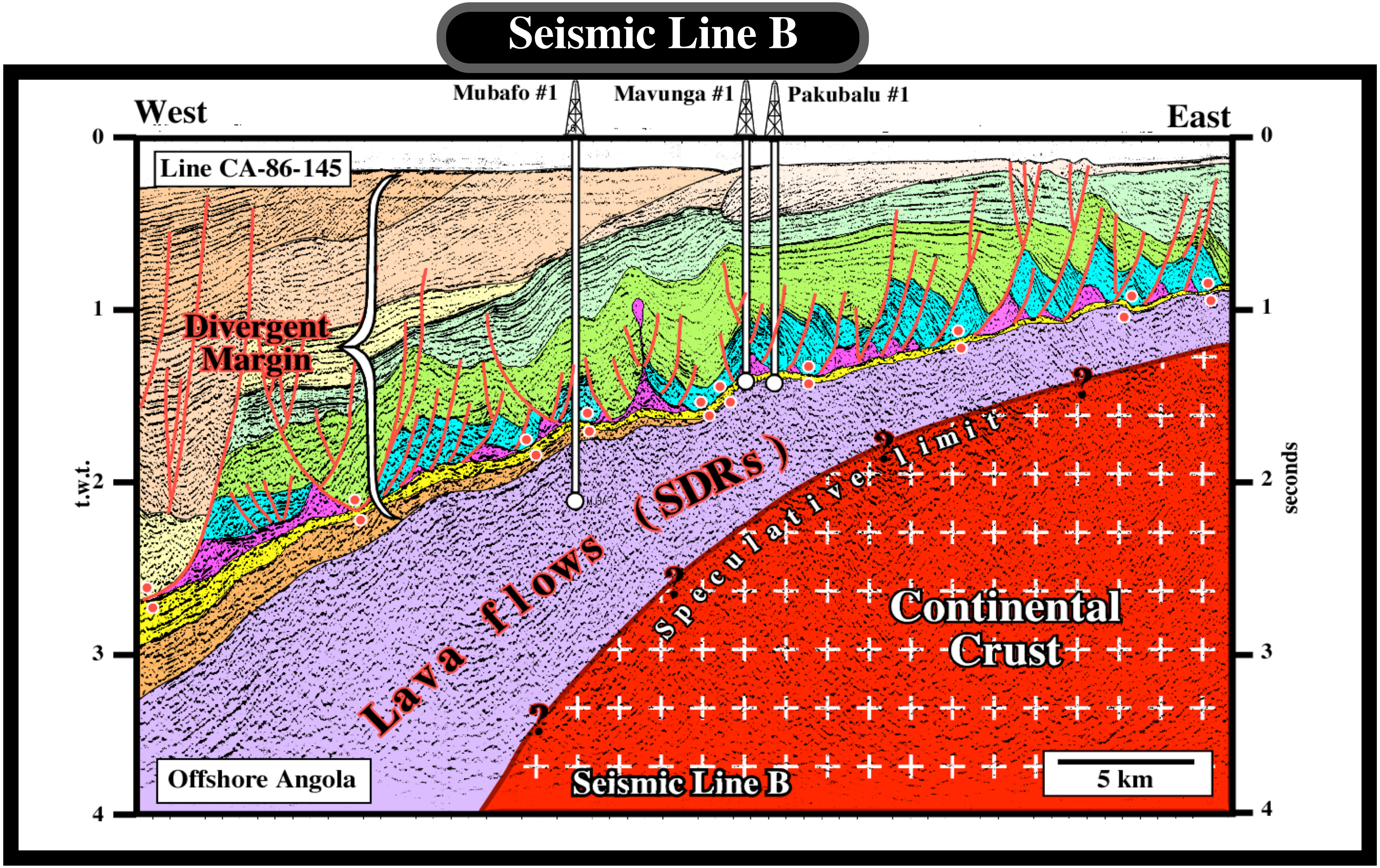


On this tentative interpretation: (i) The tectonic disharmony (bottom of the salt layer and salt welds) is evident, since the overlying sediments are appreciably deformed, while the underlain are undeformed, (ii) The breakup unconformity (BUU) corresponds to the bottom of the margin sub-salt sediments (in yellow), which, on the left, overly the basement and rift-type sediments and, on central and right part, overly the subaerial volcanism (lava flows). The limit between the continental and volcanic crust corresponds to the Mijuca FZ. Lukunga ≠1 recognized the basement and rift-type sediments, while Safukala ≠1 recognized subaerial vulcanism below the margin sub-salt sediments (Cuvo Formation = Chela formation).

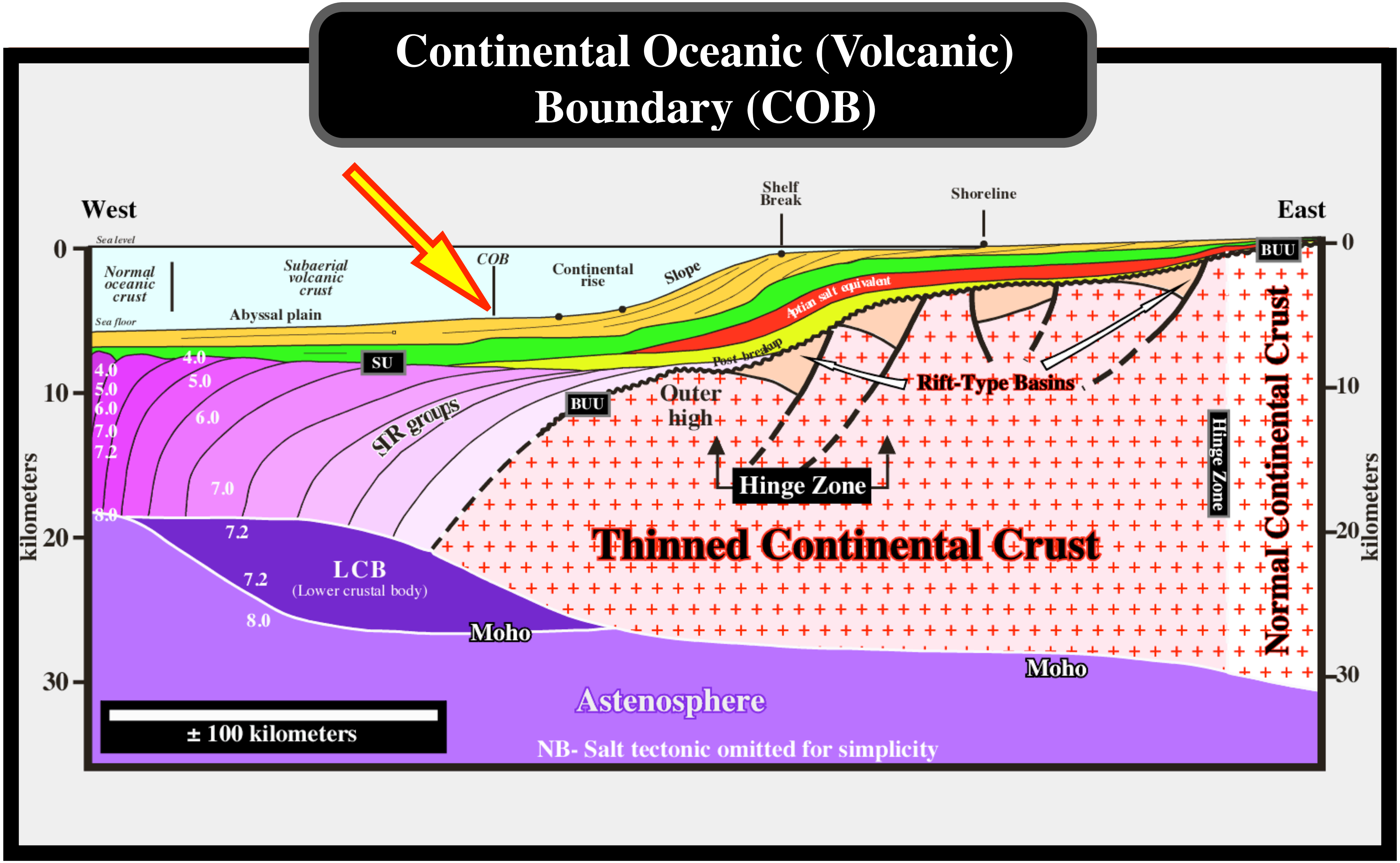
Seismic Line A



This close-up clearly illustrates the limit between the continental and the volcanic crust. Rift-type basins are possible in the continental crustal and impossible in the volcanic crust (subaerial and oceanic). Lifuti ≠1 and Safukala ≠1 recognized below the margin sub-salt sediments and post breakup lavas flows. Even without the seismic data, that is to say, just with the wells' results, the Mijuca FZ could be roughly located. The interesting thing of this close-up is not only the abrupt disappearing of the reflections induced by the rift-type sediments, but the compressional structure above the fracture zone as well. Such a structure was induced by reactivation of the FZ probably by oceanic ridge pushing.

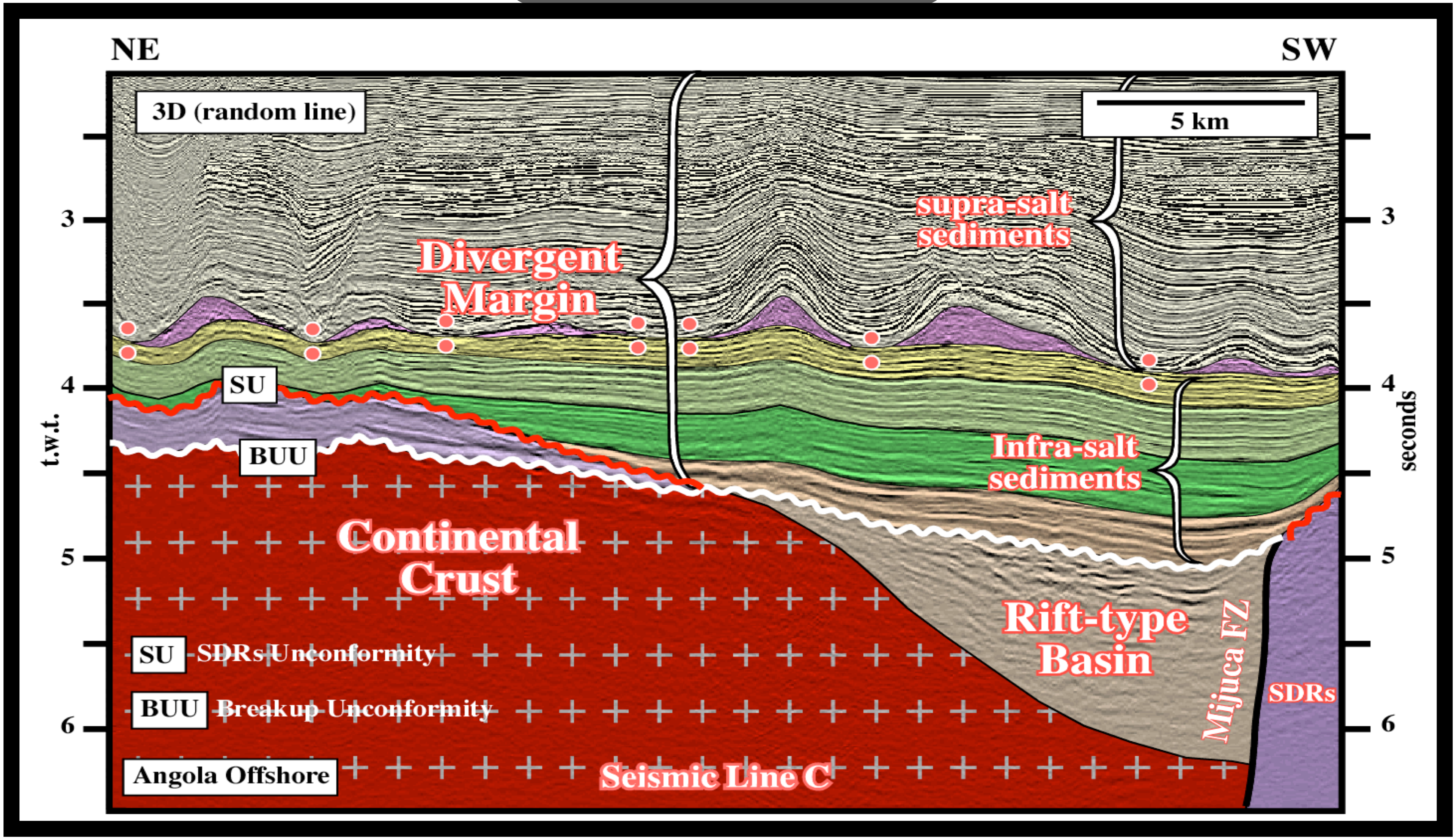


On this tentative interpretation of the seismic line B (perpendicular to the previous line), just a geological province is recognized. It depicts several important points: (i) The seaward dipping and thickening reflectors associated with the post-breakup lavas flows are obvious, (ii) The limit between the continental and volcanic crust is speculative, (iii) The margin sub-salt sediments strongly thick westward, (iv) Below the sandstone Cuvo sediments (in yellow), an organic rich shale interval (in brown, probably with lacustrine shales) is often well developed above subaerial volcanism. As we will see later, this post-breakup interval has an excellent generating petroleum potential.

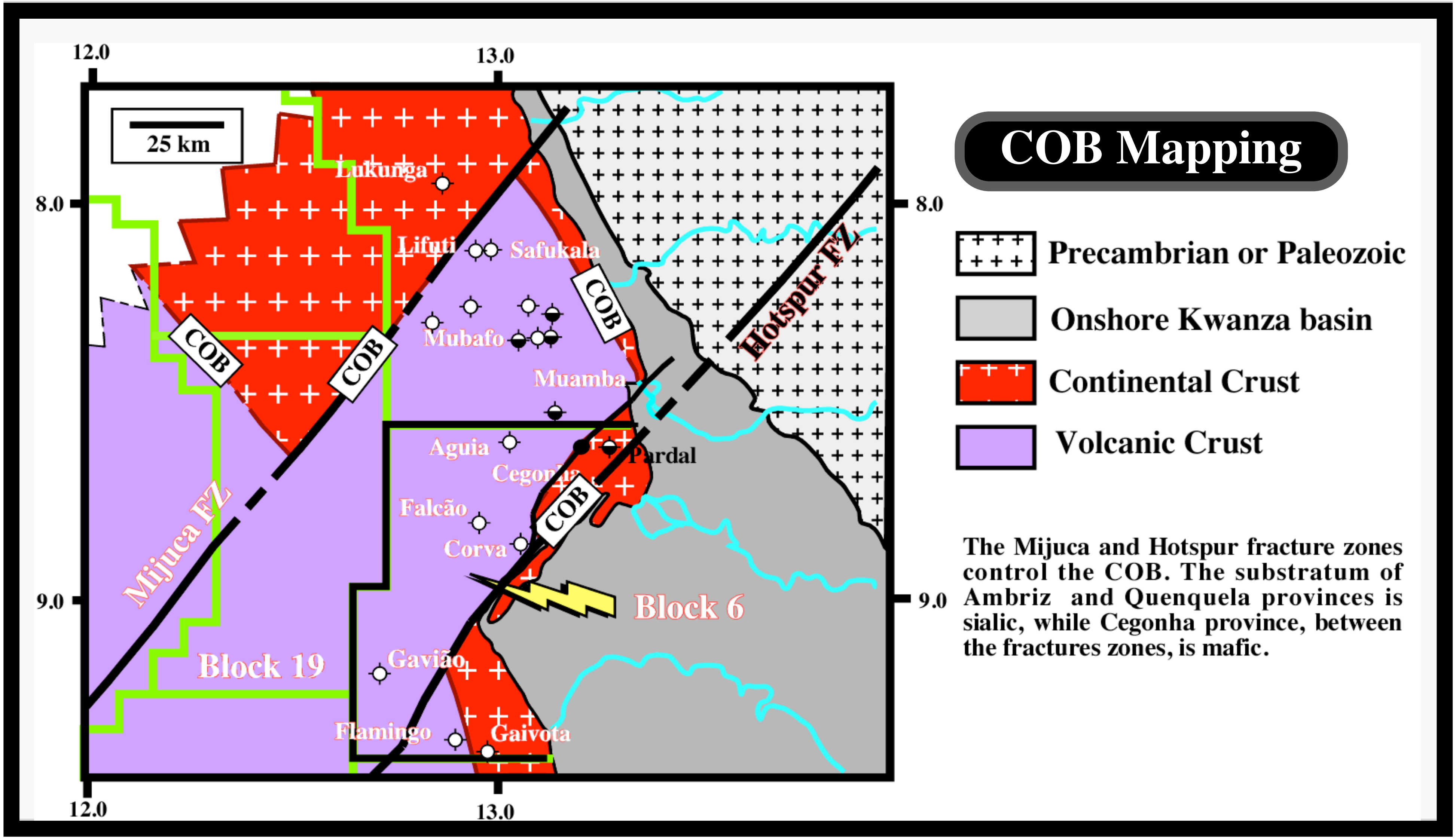


This schematic cross-section illustrates the range of uncertainty on the location of the continental-volcanic boundary. The lavas flows, after being deposited sub-horizontally (thinning landward), tilt progressively seaward (due to the loading of younger flows). However, the interface between the continental and volcanic material never reaching a sub-vertical geometry. As the distal lava flows can overly and fossilize the central rift-type basins, it has been suggested, by pure convention, to position the limit between the two realms at the vertical of the thickness of 1-2 km of the SDRs. Fortunately, as illustrated next, in particular situation, the geometry of the interface is almost vertical and so the accuracy of the picking much higher.

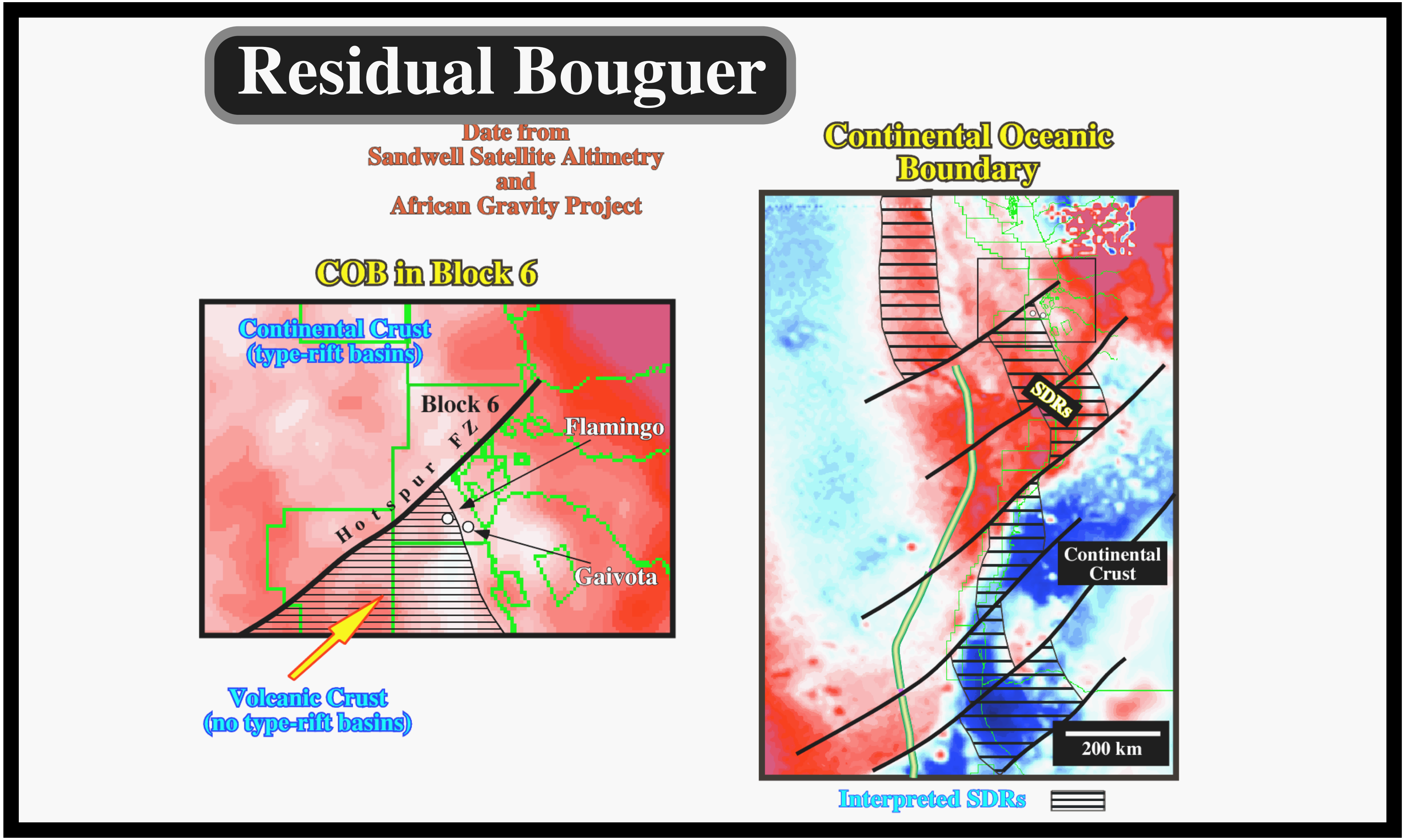
Seismic Line C



This tentative interpretation summarizes all major points discussed so far: (i) A rift-type basin with potential source-rocks is developed in the continental crust, (ii) The continental-volcanic boundary is obvious (Mijuca FZ), (iii) The lava flows overly the breakup unconformity (BUU), (iv) The interface between deformed and undeformed sediments corresponds to the salt induced tectonic disharmony, (v) A thick margin sub-salt interval probably with a certain petroleum potential was deposited above the SDR unconformity (SU), in the left, and above the top of the rift-type sediments (breakup unconformity BUU), in the right, (vi) The Cuvo formation (in yellow).

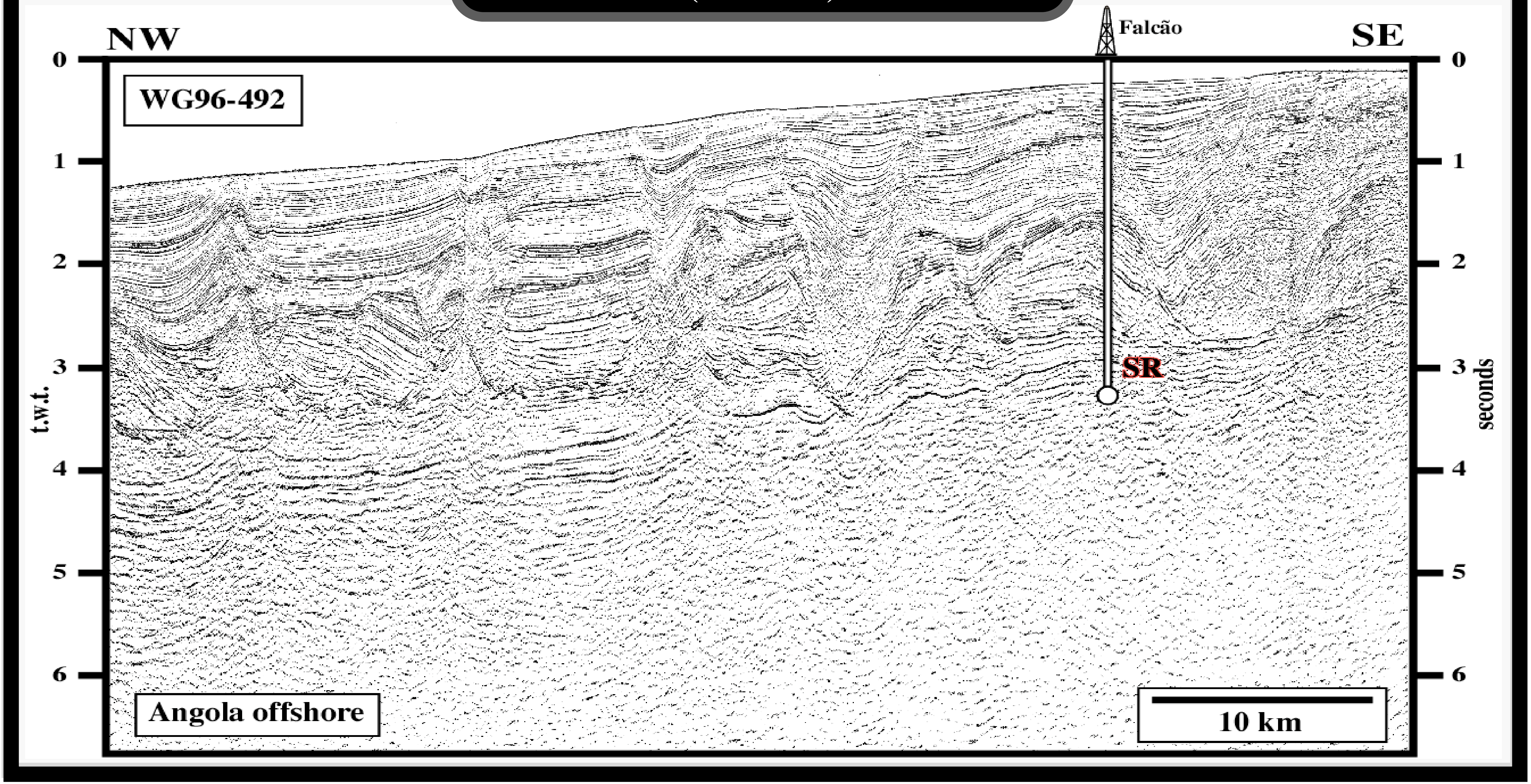


Taking into account the tentative interpretations of the seismic lines, the more likely mapping of the continental-volcanic boundary can be proposed as depicted. Such a mapping, which is not refuted by the the results of the wells, clearly suggests that just taking into account the infrasalt intervals (the organic matter of potential supra-salt source-rocks is immature) different geological provinces and potential petroleum systems can be recognized in blocks 6, 19 and 5. On the other hand, this map, around the Mijuca and Hotspur fractures zones is not refuted by the residual Bouguer, as illustrated in next plate.

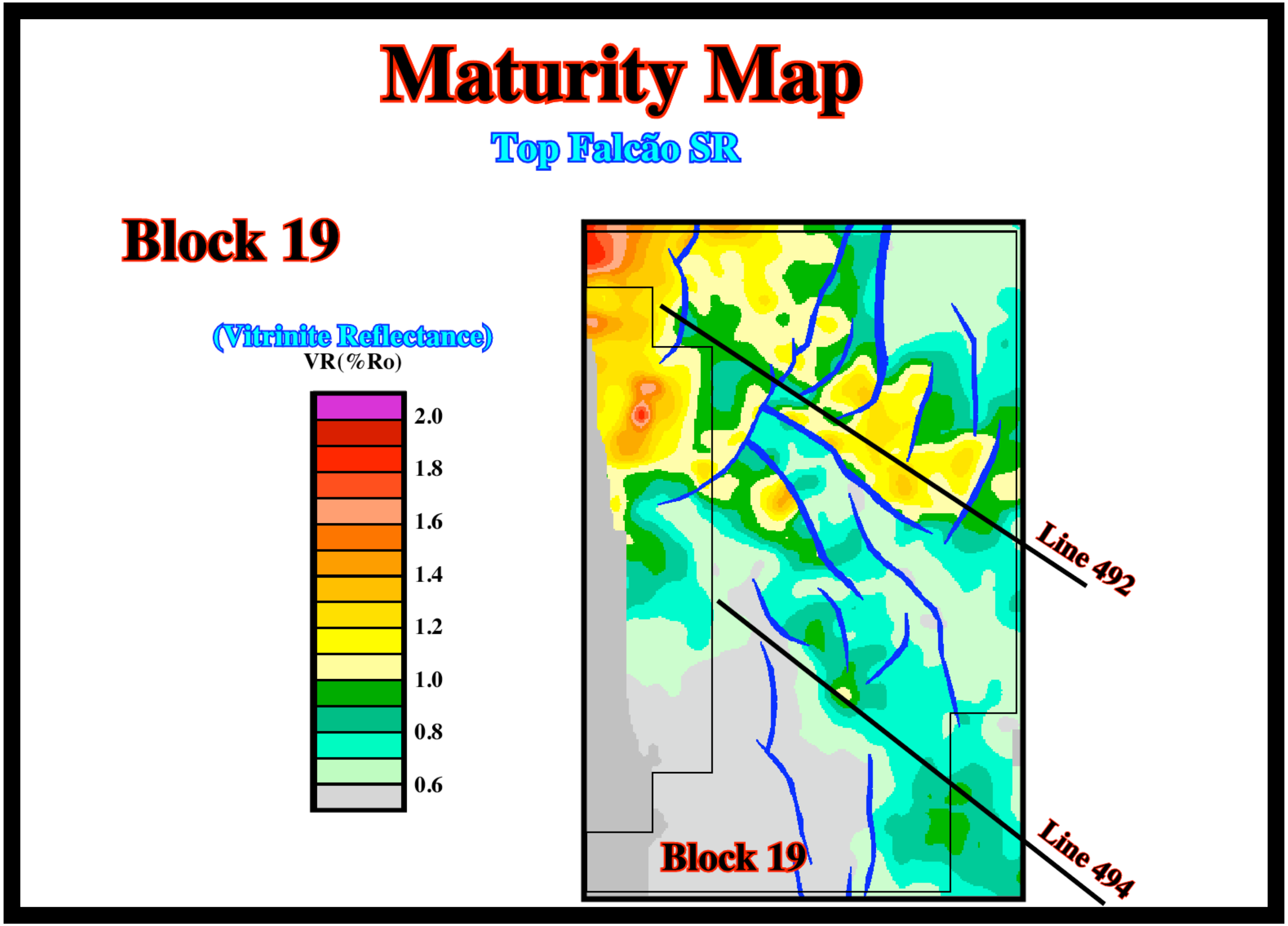


The residual Bouguer is used here to test, that is to say, to try to refute the mapping of the continent-volcanic boundary proposed previously, as well as the location of the major fracture zones, which, in fact, control the petroleum systems. Indeed, not only they control the location of the rift-type basins (pre-breakup lacustrine source rocks), but the location of the prolific turbiditic reservoirs in deep-water as well. In block 6 and 19 (on the left), the Hotspur FZ, divides the blocks into two different geological provinces. However, as shown previously, in the volcanic realm excellent margin sub-salt source-rocks were deposited as corroborated next.

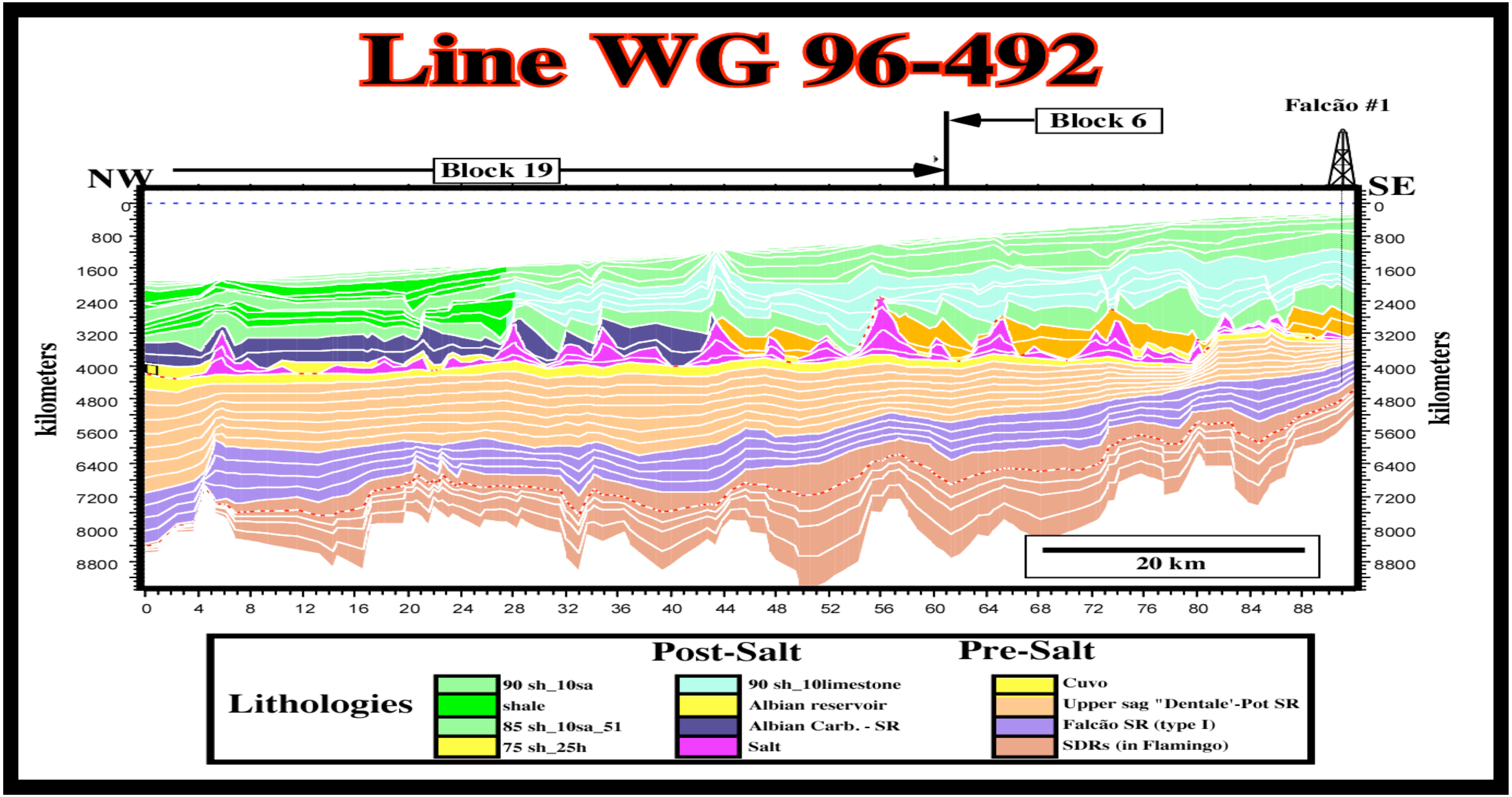
Lower Margin Source Rocks
(Infrasalt)



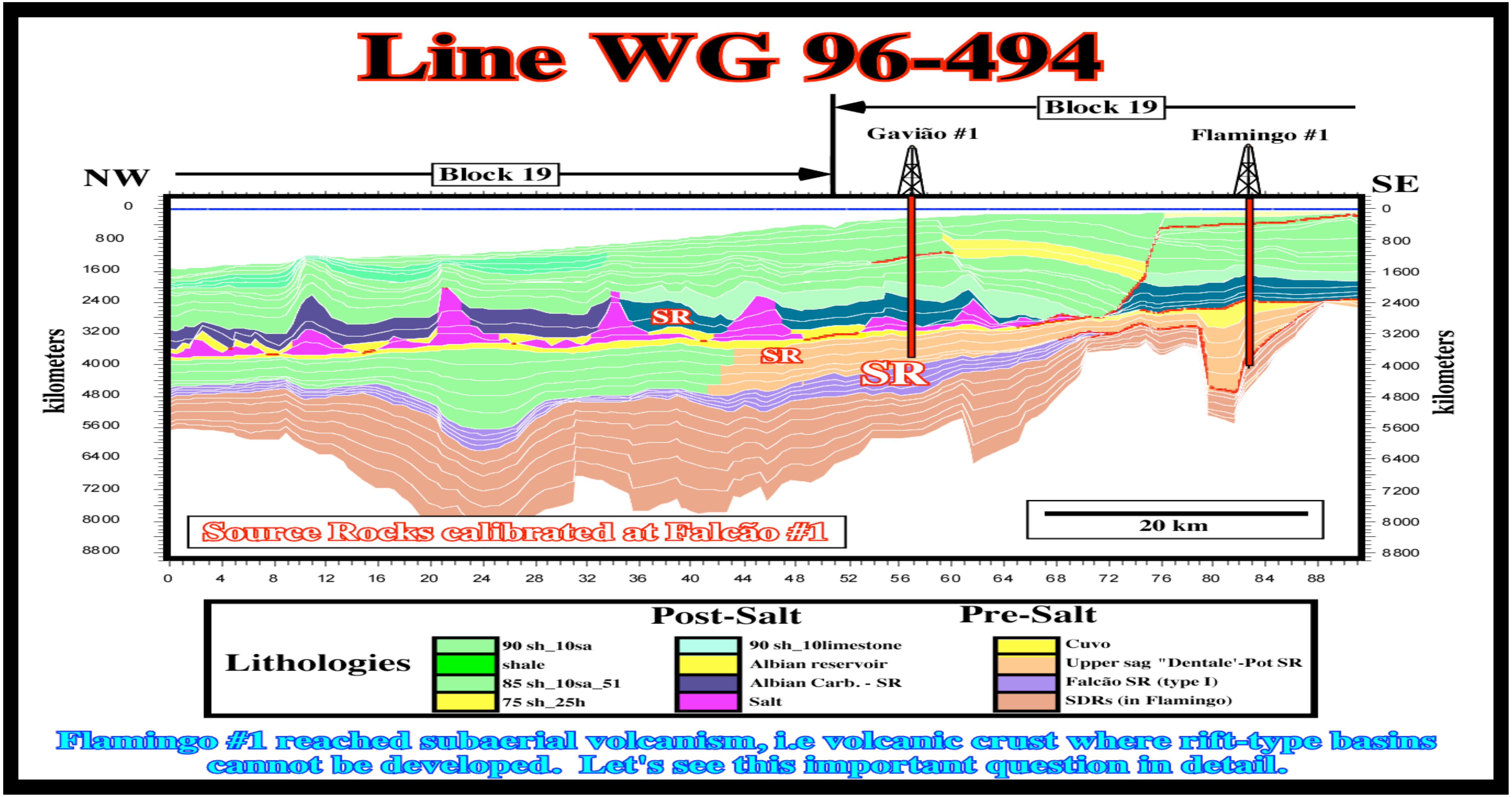
This seismic line through Falcão well, allows the calibration of the margin sub-salt interval deposited above the SDRs (lavas flows), which are easily recognized in the right end of the line. The SDRs were not corroborate by the well's results, since the well was stopped in the margin sub-salt interval, which showed an excellent generating petroleum potential. Indeed, as illustrated next, the maturity map (vitrinite reflectance) of the organic rich shaly horizons indicates the the zones where the organic matter reached maturation and generated hydrocarbons.



Two seismic line were chosen to test the maturity of the organic matter of the potential margin sub-salt source rocks, i.e., the source rocks posterior to the breakup of the lithosphere and overlying the lava flows. It is important to notice that such organic rich sedimentary intervals overly the SDRs, which means that the rift-type basins are either absent or too deep below the SDRs, and so, probably without petroleum potential. In other words, this potential source rocks are in a similar stratigraphic position as the Campos sub-salt hyper-saline source-rocks, in Brazil, but they are not rift-type basin source rocks, even if their organic matter is type I.

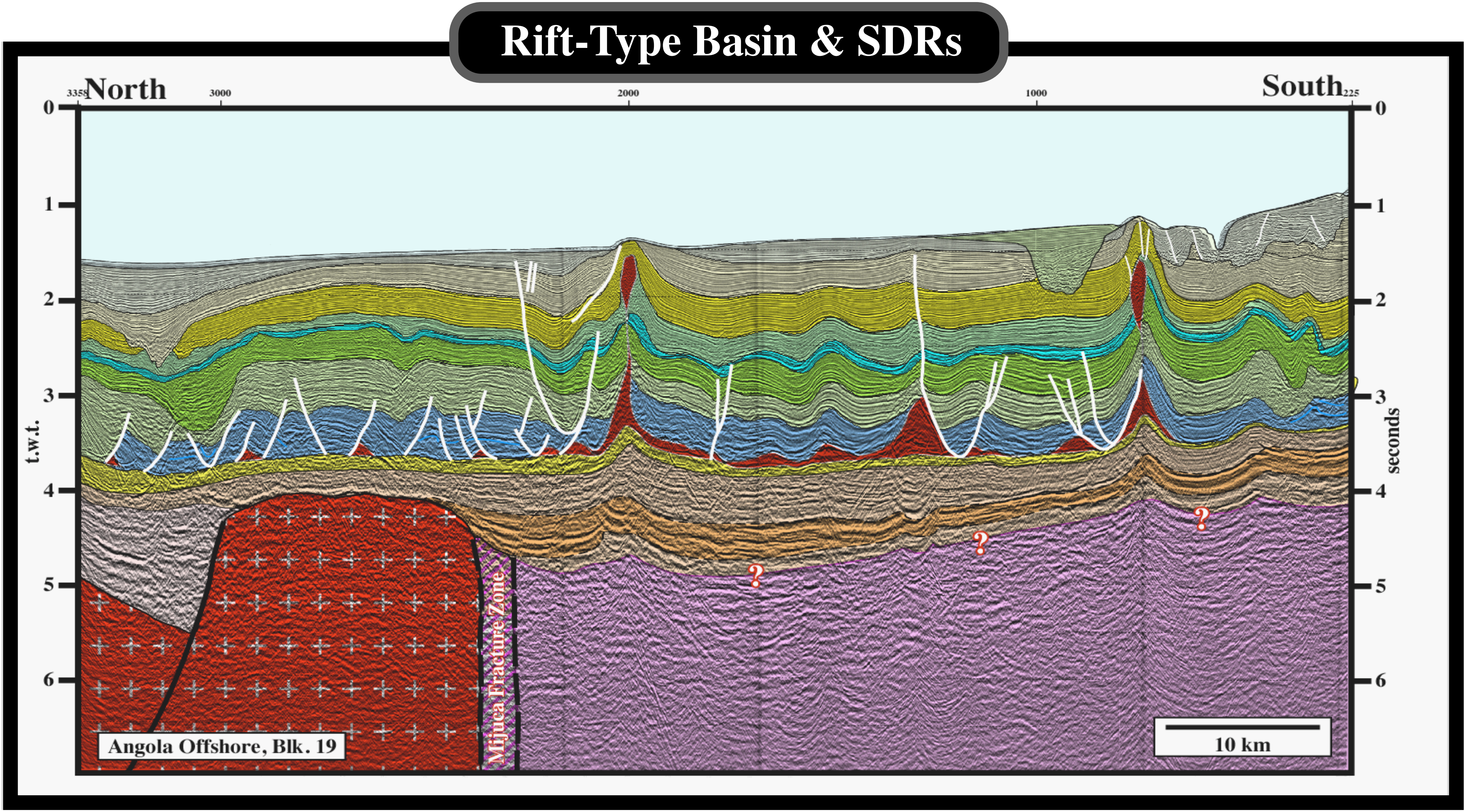


On this tentative interpretation of the seismic line WG 96-492, the geological calibration is done by the results of Falcão ≠1, drilled in block 6. The well recognized in the margin sub-salt sediments an organic rich interval (in purple) with excellent petrophysical characteristics of source rocks. This rich organic interval (organic matter type I), which lies on the subaerial lava flows (SDRs), seems to be developed in a lacustrine environment. The break unconformity (no visible on the line) is below the lava flows. Unfortunately, on this area, there are no potential traps either in sub-salt or supra-salt sediments. The generated hydrocarbon seem to have migrated toward the borders of the basin, where they form huge asphaltic accumulations.



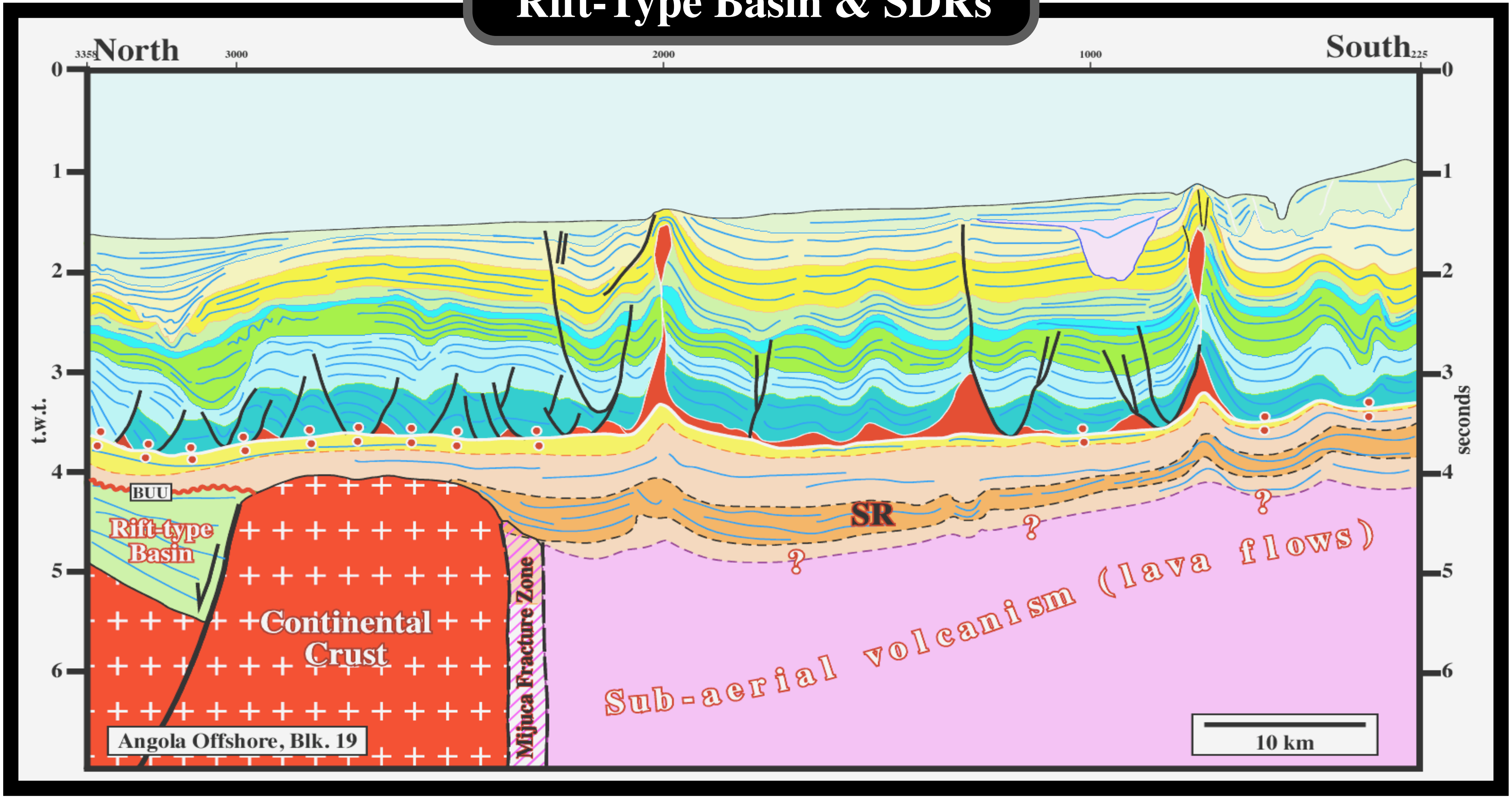
On this interpretation, Gavião and Flamingo wells are not in block 19, but in block 6. Flamingo was stopped in the lava flows and, as depicted, the Gavião well did not reached the organic rich interval recognized in Falcão well. The important point is that, in the offshore Kwanza, the margin sub-salt interval overlying the post-breakup lava flows (see next seismic lines) is often quite thick and with lacustrine intervals rich in organic matter. These potential sub-salt source-rocks intervals can be correlated with the conventional source-rocks o f Campos and Santos basin. On the contrary, they are not correlable with the rift-type basins source-rocks of the Tupi discovery in Santos basin.

Rift-Type Basin & SDRs



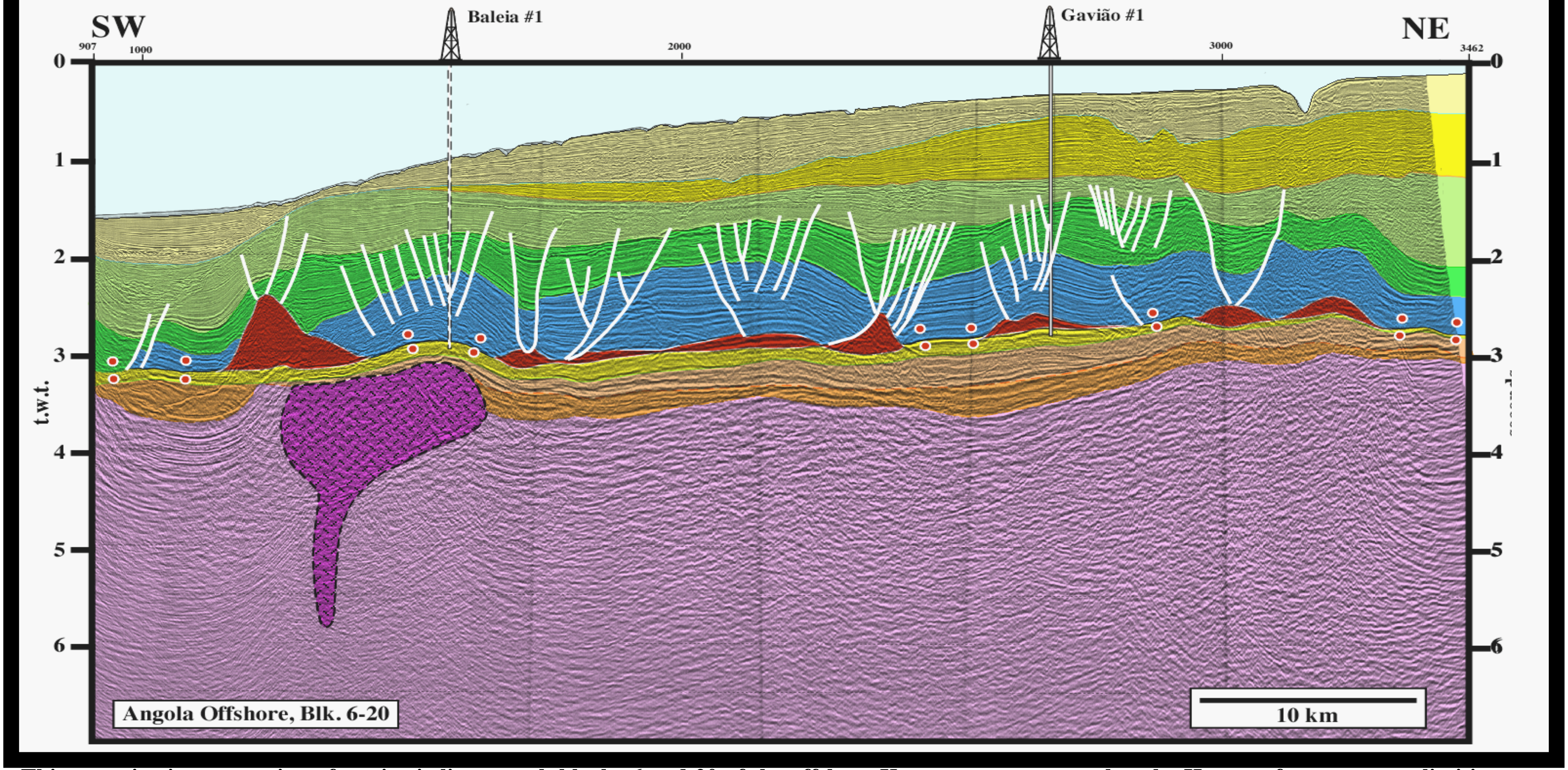
On this tentative interpretation of a seismic line from the block 19, the relationships between the development of the organic rich margin sub-salt interval and the post-breakup lava flows (SDRs) are obvious. The Mijuca fracture zone separates the continental crust, where rift-type basins developed before the breakup of the lithosphere and the subaerial lava flows. The organic rich margin sub-salt interval (in brown) is easily recognized above the lava flows, but it is totally absent northward of the Mijuca FZ. Just the upper most margin sub-salt intervals (in yellow and in light brown) were deposited on the continental crust (rift-type sediments and basement), as better illustrated in the next plate.

Rift-Type Basin & SDRs



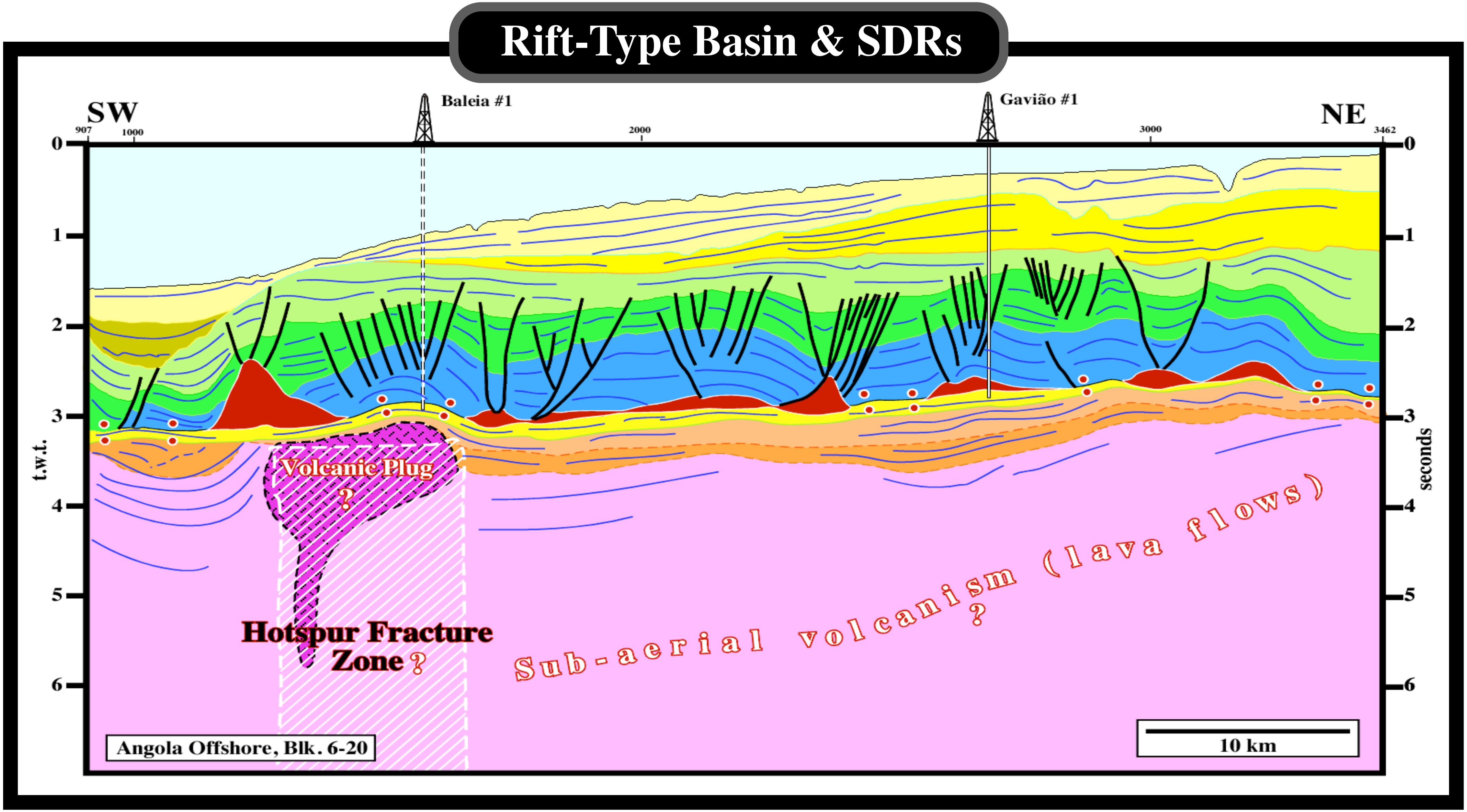
A rift-type basin, where lacustrine source rocks are often deposited, was developed northward of a buried hill of the basement, which southern flank fits with the Mijuca fracture zone. The breakup unconformity (BUU) is just visible northward of the Mijuca FZ, above the rift-type sediments and the basement. Southward, it is not visible. It corresponds to the bottom of the lava flows. The organic rich sub-salt interval is readily visible just above the lava flows. Similarly, the salt induced tectonic disharmony, which separates undeformed sub-salt sediments (their wavy geometry is induced by lateral velocity changes in the overlying sediments) from deformed post salt sediments is also crystal clear.

Rift-Type Basin & SDRs

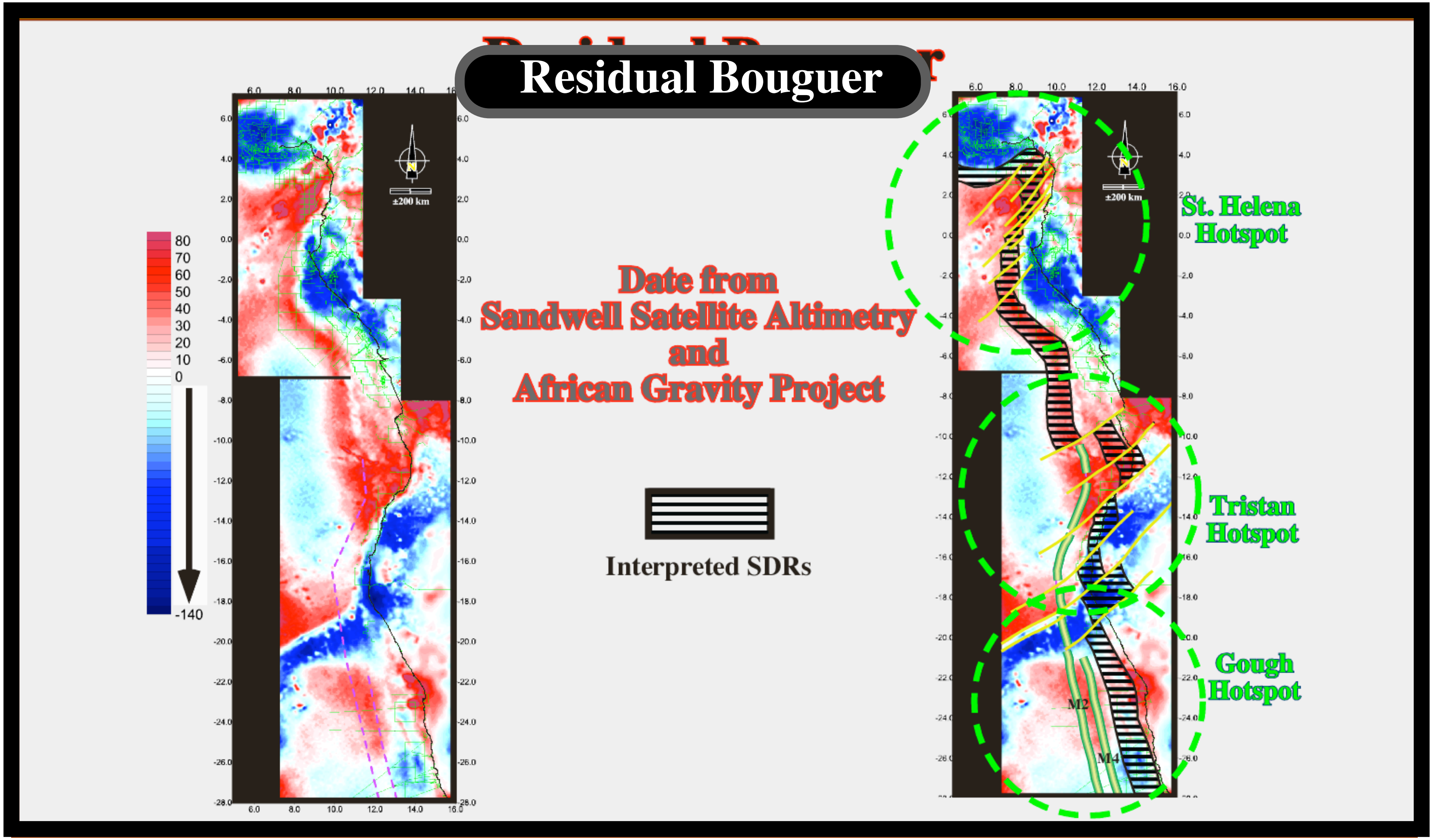


This tentative interpretation of a seismic line trough blocks 6 and 20 of the offshore Kwanza, one can see that the Hotspur fracture zone, limiting two volcanic geological province, is enhanced by a volcanic plug. Admittedly, in these province there are no rift-type basins, which, as said previously, can just develop in the continental crust by lengthening of the lithosphere. Below the tectonic disharmony (bottom of the salt layer and salt welds), three seismic interval are easily recognized. The lower one correlates with the Falcão source rocks (block 6), but apparently, i.e., taking into account the well results, its petroleum potential seems to be very poor.

Rift-Type Basin & SDRs

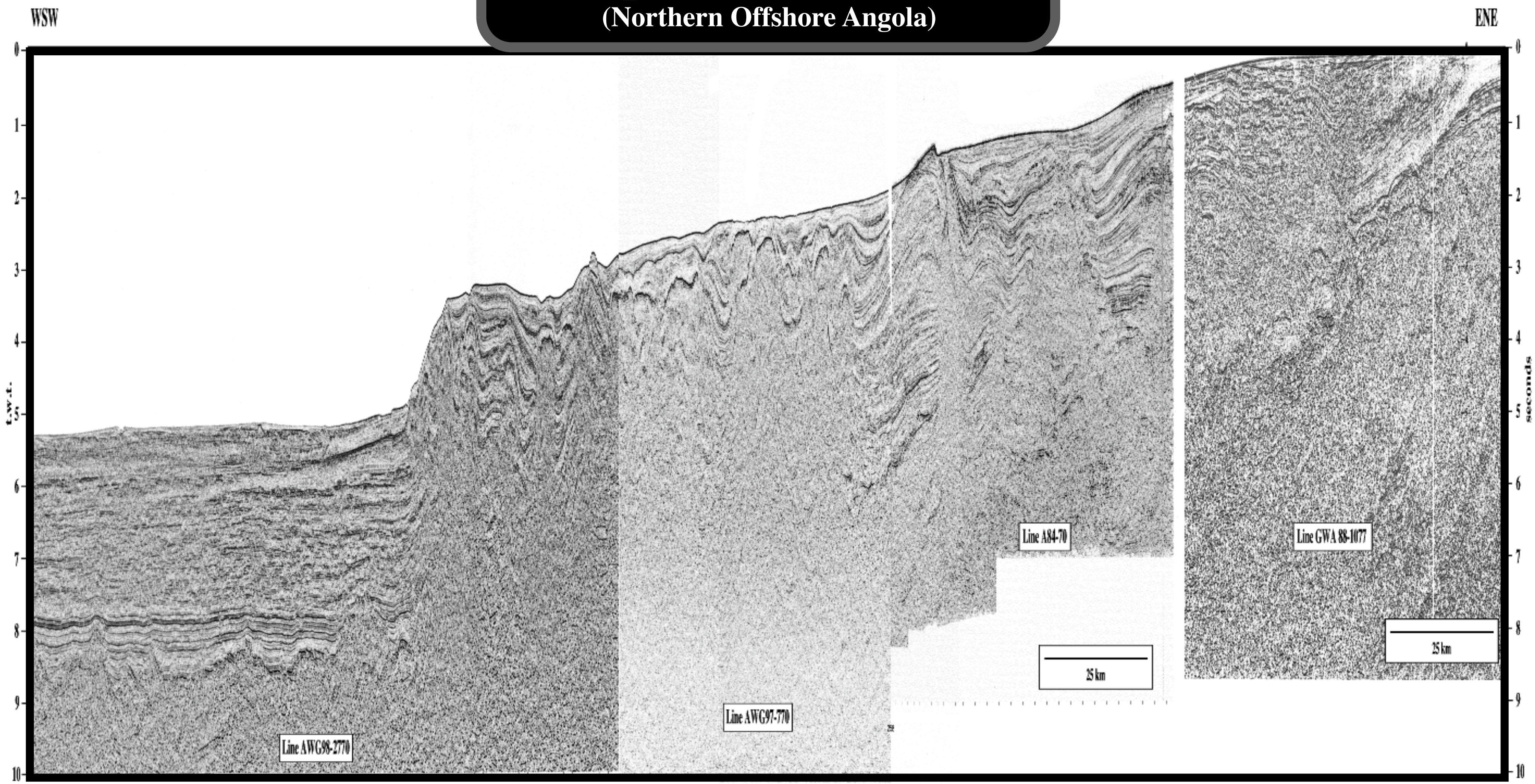


The Hotspur fracture zone seems to be reactivated and intruded by volcanism. The deformation of the lava flows reflectors (SDRs) in the western geological province, as the structural high of the tectonic disharmony at the vertical of the fracture zones, corroborate the hypothesis of a reactivation. The negative results of the wells can be explained by: (i) The organic matter of the post salt source-rocks (dark blue) is immature and the margin sub-salt source-rocks are absent or (ii) The organic matter of the both generating subsystems (post and sub-salt) is immature. Any of these hypotheses can be refuted. Indeed, the wells did not reach the lowermost margin sub-salt interval, which burial seems to be not enough to mature the organic matter.

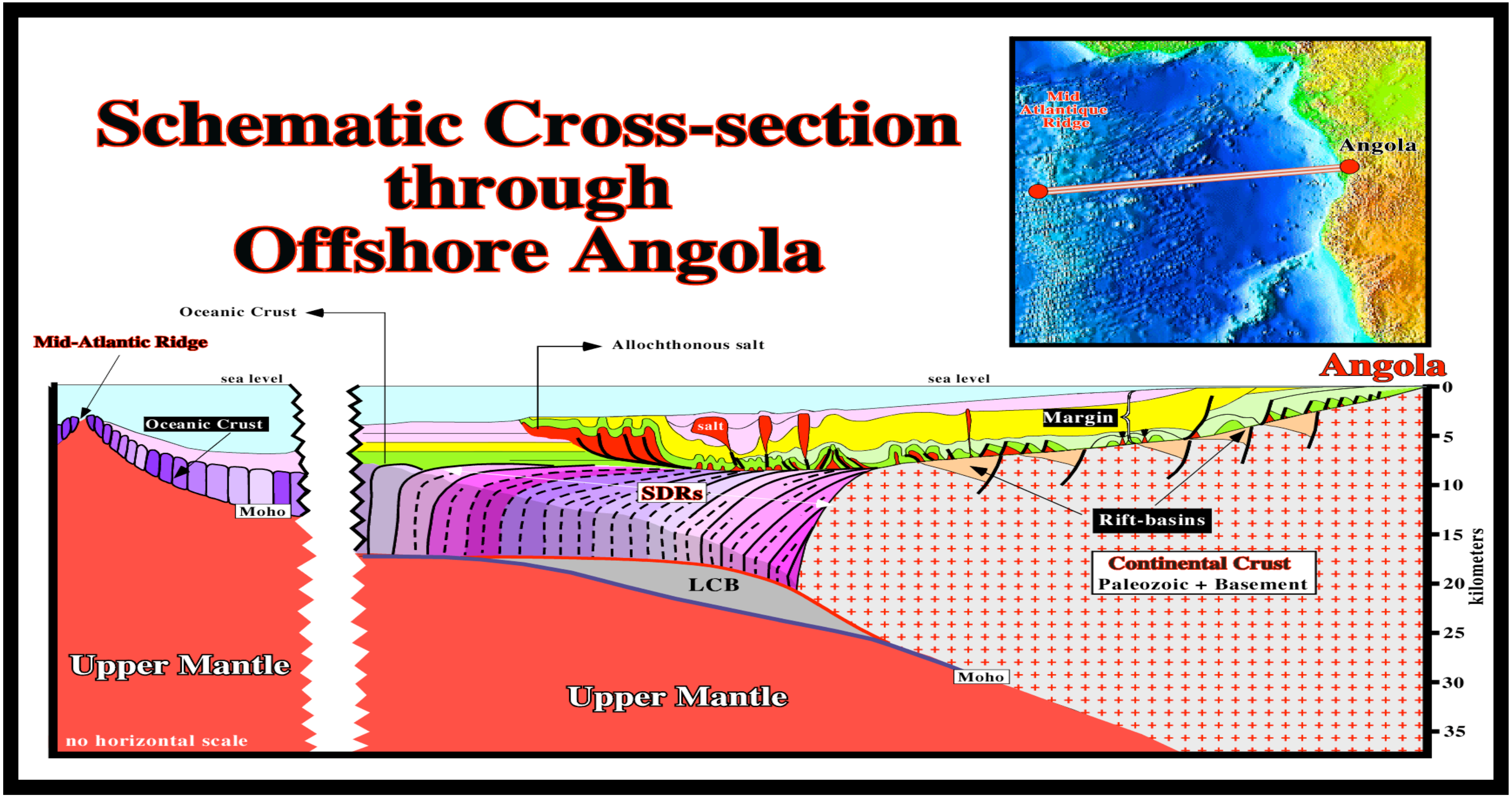


The residual Bouguer allows a first test of the mapping of the continental-volcanic boundary (continental /subaerial volcanic crust) and the trace of the "major" fractures zones done with seismic data and the results of the wells. The lavas flows between Gulf of Nigeria and Orange Basin (Namibia) are associated with three hotspots: (i) St. Helena, (ii) Tristan and (iii) Gough. Those found in Kwanza and Congo Basins are related with the Tristan hotspot. The petroleum interest of such a map is to hypothesize on the more likely potential source-rocks. If the substratum of an exploration block in the deep offshore of Angola is formed by SDRs, one can hypothesize that rift-type generating subsystems are absent and, the more likely source-rocks are either the marine source-rocks, associated with the Cretaceous transgression, or the Tertiary dispersive deep-water source-rocks.

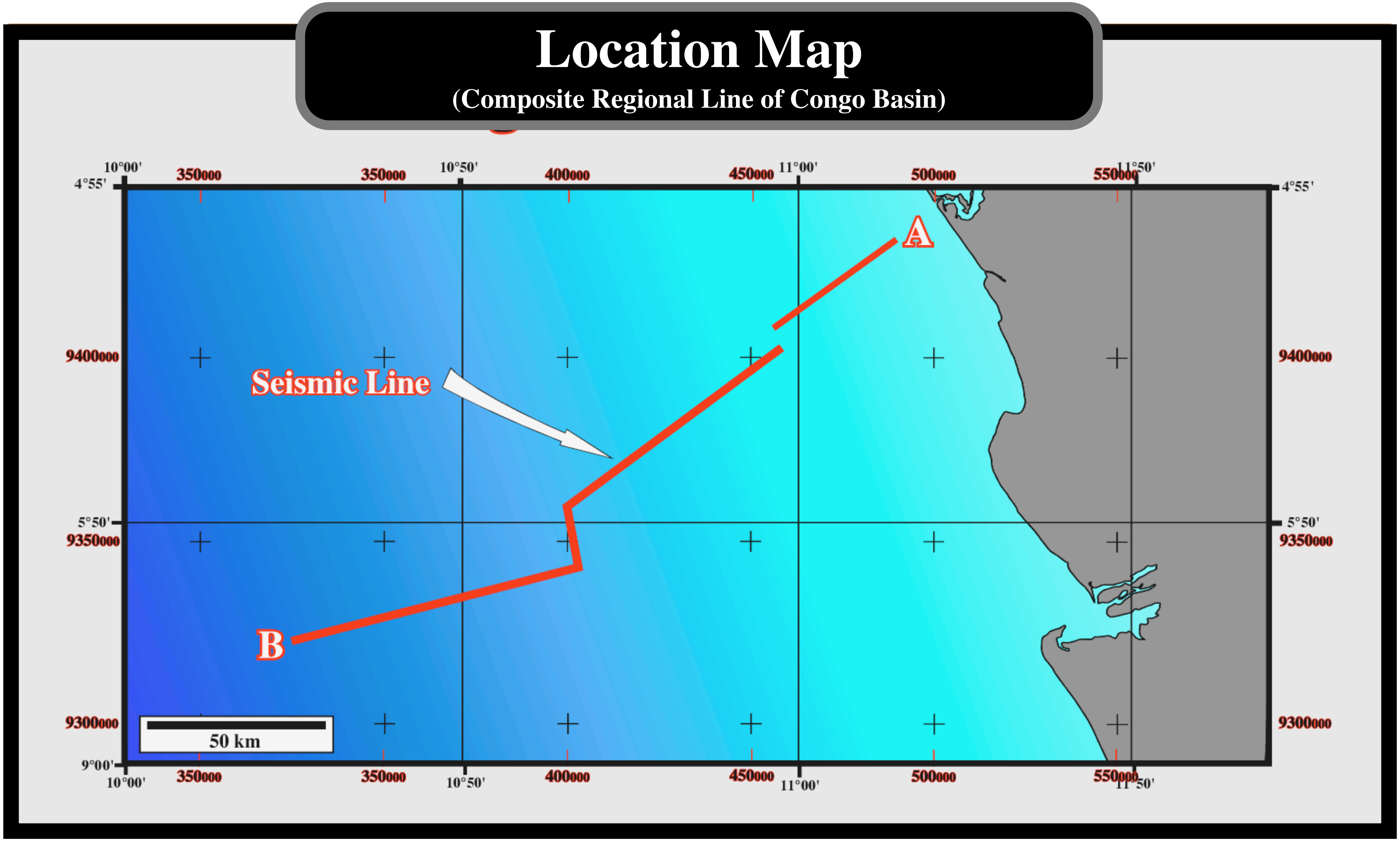
Composite Seismic Line
(Northern Offshore Angola)



On this regional seismic line of Congo basin, the oceanic crust is obvious, in the left part of the the line. Subsequently, the rift-type generating subsystems, i.e the Bucomazi source-rocks are absent and the margin-source rocks immature (the water depth has non contribution on the maturation of the organic matter). On the contrary, in the right end of the line, rift-type basin are present. So, the Bucomazi source-rocks exist and their organic matter is mature (take into account 1.5- 2.5 km of uplift of the border of the margin). The transgressive source-rocks (Iabe formation) are also present. In central part of the line, the SDRs are easily recognized. They are quite thick. So, the more likely generating subsystems are the transgressive (Cretaceous) and the dispersive (Tertiary).

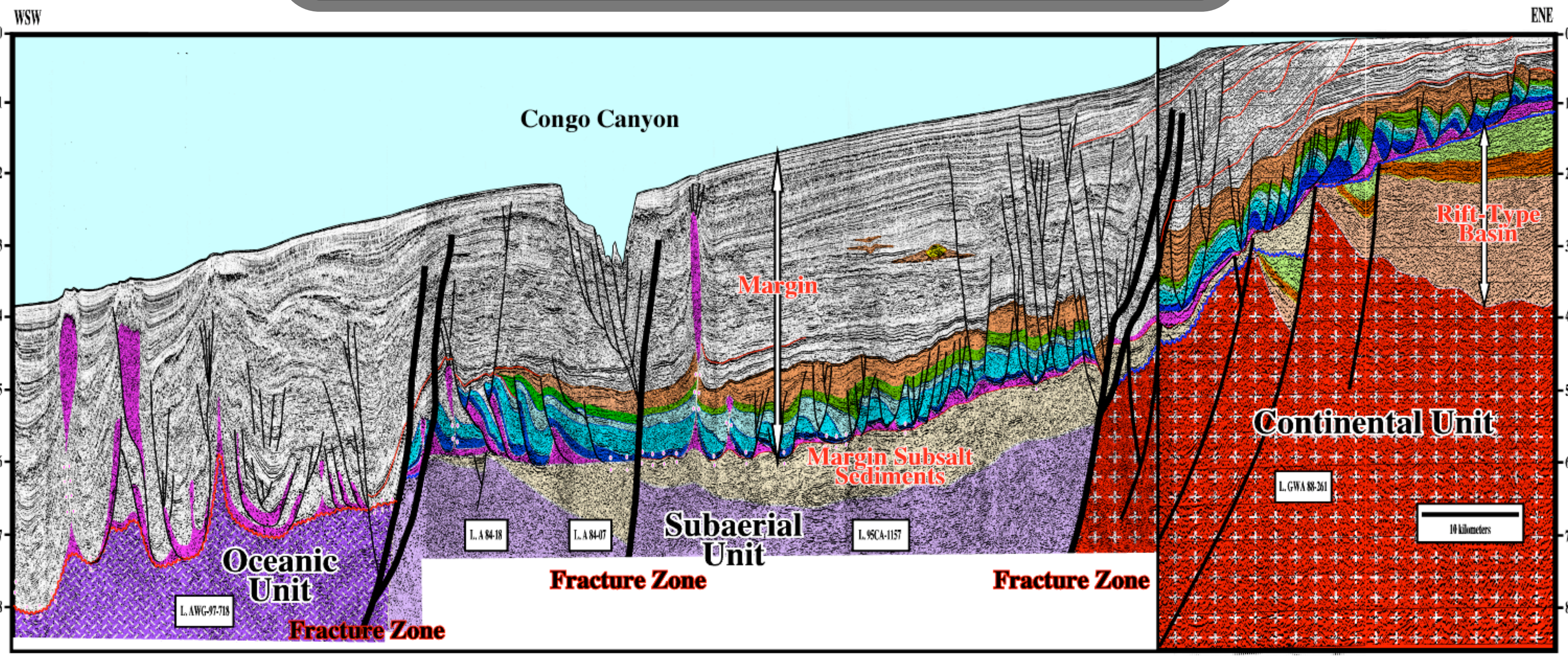


The more likely generating subsystem in the southern Congo basin (offshore Angola) are easily predicted using this regional cross-section (based in a composite regional line). Three different crustal unities form the substratum: (i) Oceanic (oceanic crust), (ii) Lava flows (subaerial crust) and (iii) Continental (continental crust). Above oceanic unit, there are no source rocks or there are immature Cretaceous transgressive source-rocks. Above the subaerial unit, there are Cretaceous transgressive, Tertiary dispersive or margin sub-salt source rocks. The organic matter of all them can mature. Above the continental unit, there are rift-type basin (Bucomazi), Cretaceous transgressive and Tertiary dispersive (in the distal area) mature generating petroleum subsystems (taking into account the uplift of the border of the basin (rift-type basins and margin).



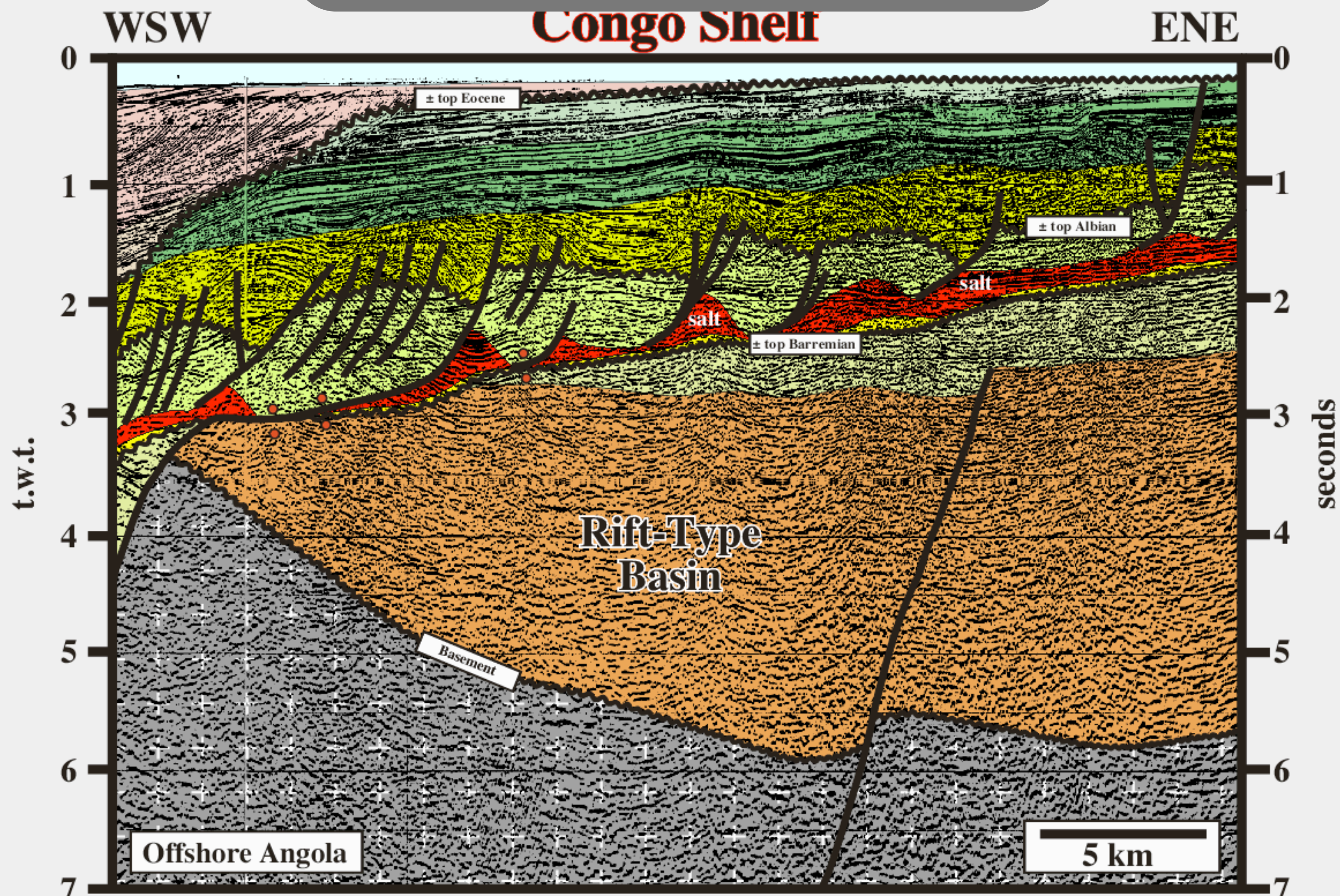
The tentative interpretation of the composite seismic line, here localized, and illustrated in the next plate, can be used to better confine the three crustal unities, which must imperatively be recognized all along of the offshore (first step of a petroleum evaluation): (i) Oceanic, (ii) Subaerial and (iii) Continental. The mapping of the crustal unities makes evident the location of the major fracture zones, which, in deep-water, control the terrigeneous influx (turbiditic currents) and the more likely potential generating petroleum subsystems within each geological province.

Composite Regional Seismic Line
(Tentative Interpretation)

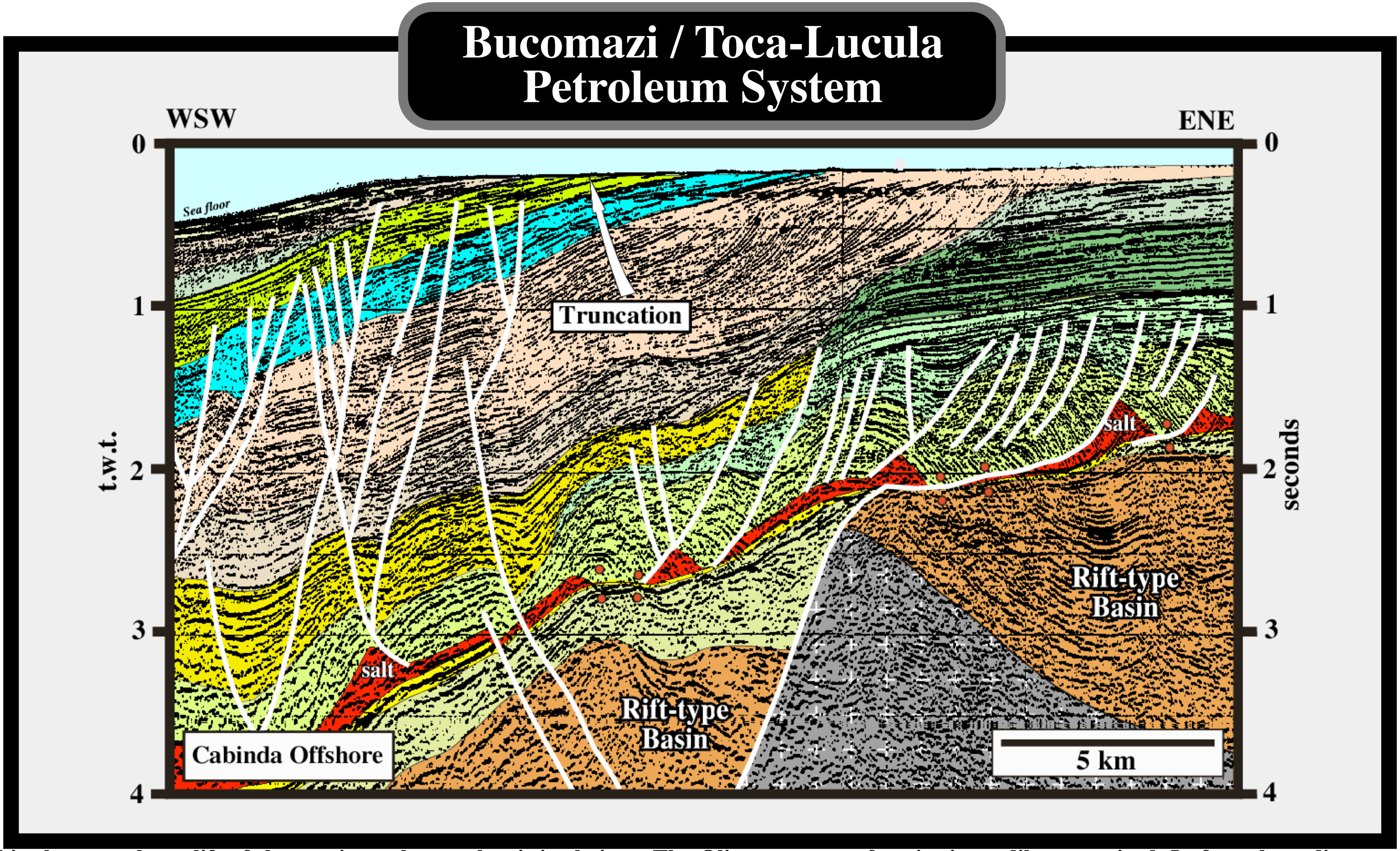


In the conventional offshore and onshore, the crustal unit composing the substratum is continental. The rift-type basins, with a landward thickening, are evident as well as the development of the lacustrine source-rocks of the Bucomazi formation (see next). In the deep offshore, the substratum is formed by subaerial vulcanism. The absence of rift type-basins is obvious as the presence of a thick margin sub-salt interval, which hydrocarbon potential still is untested. In the ultra-deep offshore, the substratum is formed by the oceanic crust. The potential generating subsystems are post-salt, i.e., Cretaceous transgressive and Tertiary dispersive. Above all these units, the marine Cretaceous generating subsystem seems to be always present, while the Tupi-equivalent, i.e. the Bucomazi generating subsystem is more likely in onshore and conventional offshore, as shown in next close-ups.

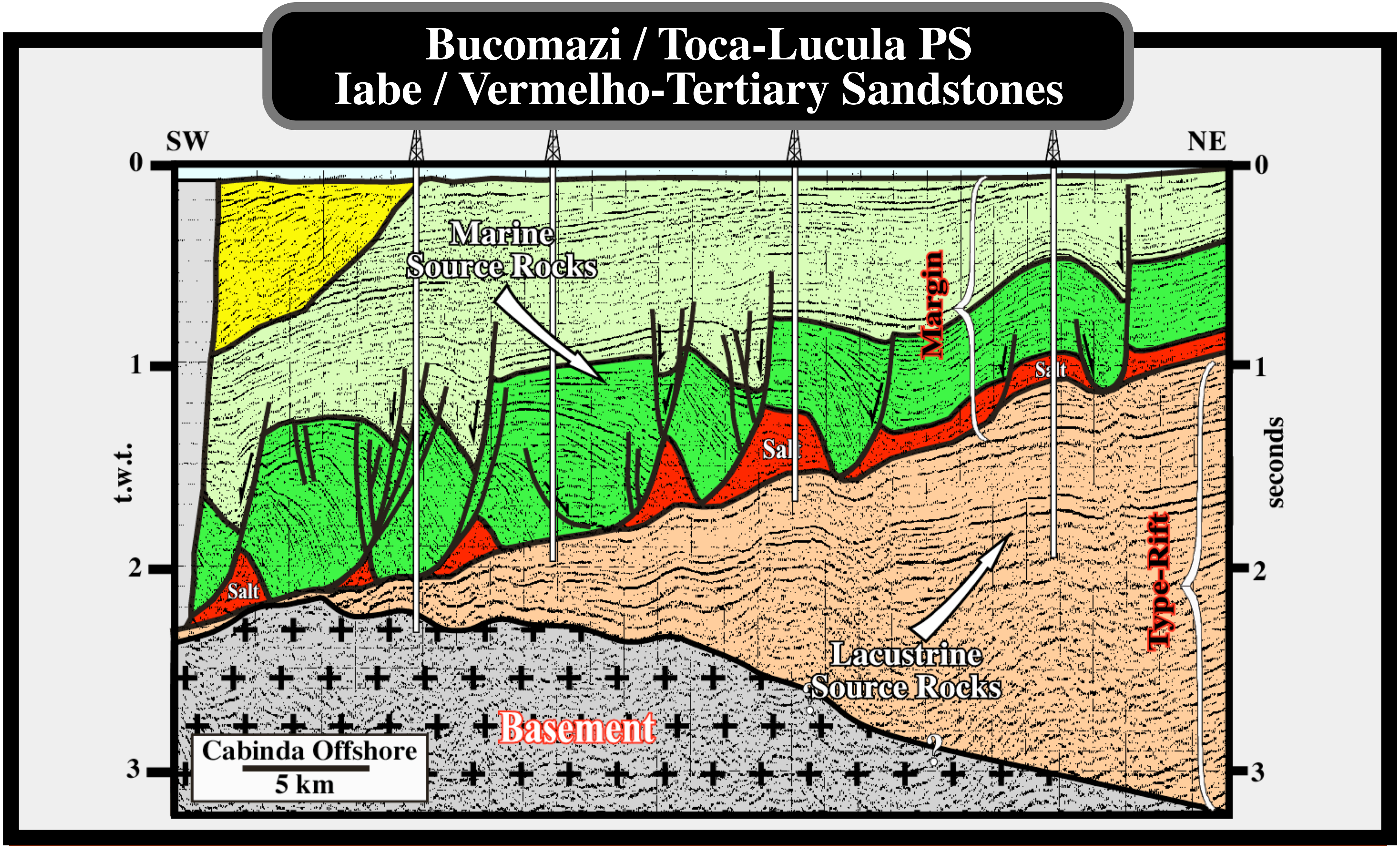
Bucomazi / Toca-Lucula Petroleum System



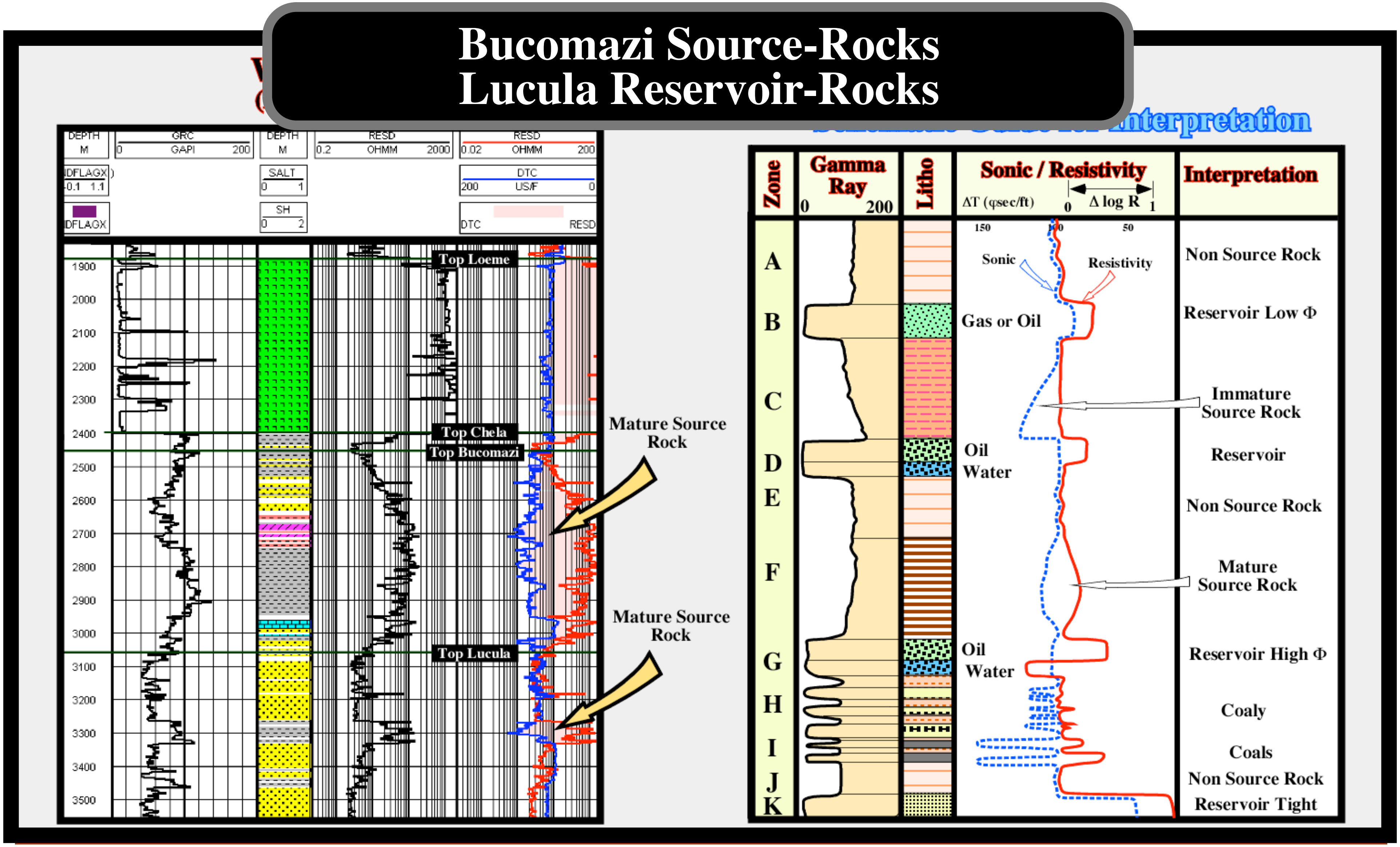
A large rift-type basin thickening landward is here evident, as the breakup unconformity (BUU). The internal configuration of the rift-type basin sediments is slightly divergent continent-ward. However, relatively thick intervals exhibit a parallel configuration (see next), which is generally associated with lacustrine intervals. In fact, a certain amount of water depth and a relatively quite environment (a lake) is necessary to develop lacustrine sediments. The rate of extension creating the rift-type basin should not be balanced by the terrigeneous influx. The reflection terminations at the sea-floor (toplaps) corroborate the uplift of the continental crustal unity, which elucidate the maturation of the organic matter of the rift-type basin source-rock sediments.



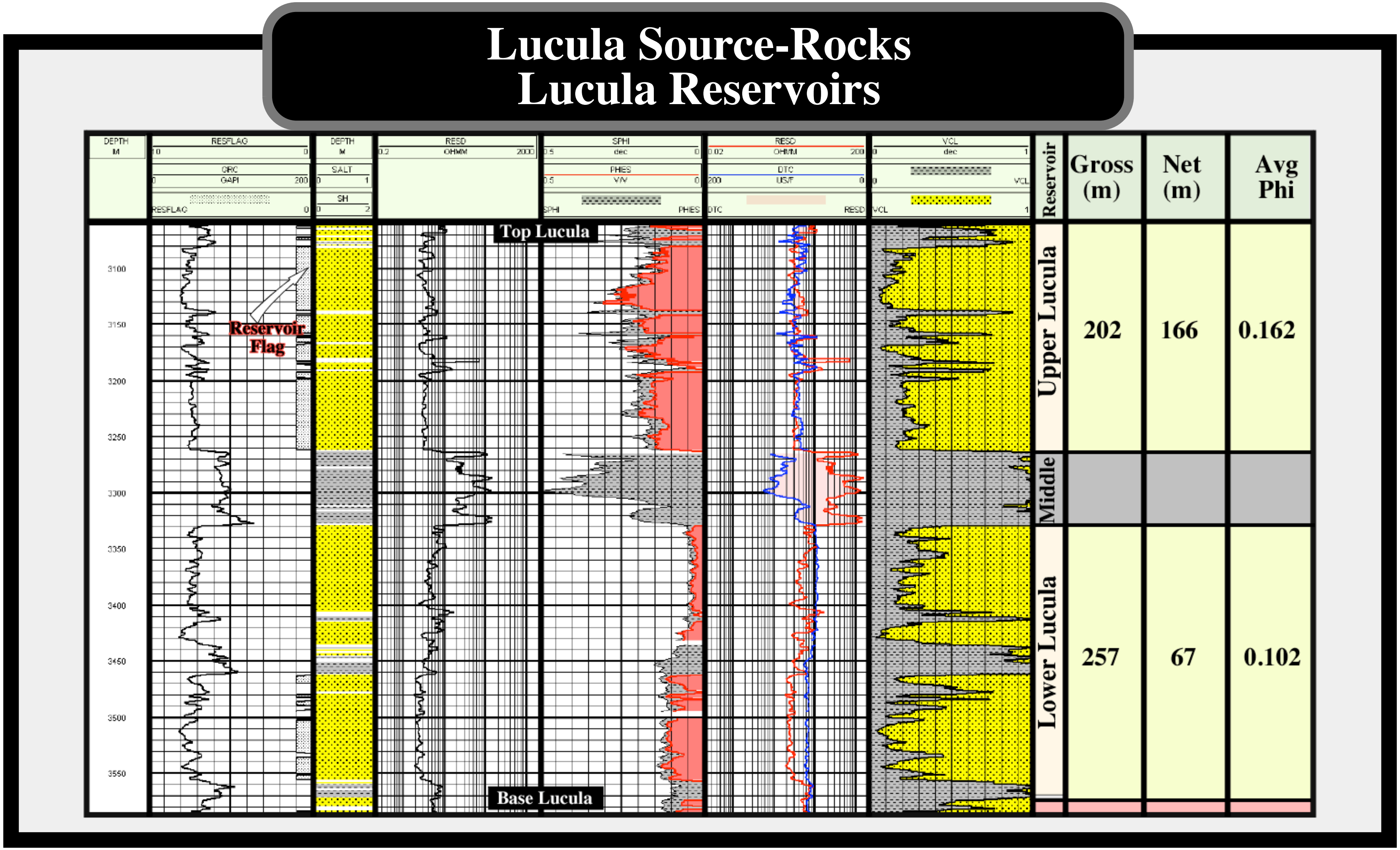
On this close-up, the uplift of the continental crustal unit is obvious. The Oligocene unconformity is readily recognized. In fact, the sediments of the Upper Cretaceous platform are truncated and fossilized by Oligocene basin floor fans and Miocene slope deposits (progradations). The salt tectonics was moderately active during the Cretaceous with creation of raft and pre-raft structures. The breakup unconformity (bottom of the margin sub-salt yellow interval, i.e., the Cuvo sandstones) is tectonically enhanced. The truncation of the upper rift-type sediments is clear. The intervals with a internal configuration parallel, i.e, the lacustrine shales of the Bucomazi, are evident, particularly in the proximal rift-type basin. Such a configuration is clear seen in next line.



On this tentative interpretation, the breakup unconformity, which here corresponds to a tectonically enhanced unconformity (angular unconformity), coincides with the salt induced tectonic disharmony. In fact, the thickness of the margin sub-salt sediments of the Chela formation (± Cuvo), recognized in the wildcats, is under seismic resolution. Within the rift-type basin, the lacustrine source-rocks intervals, i.e the lacustrine shales of the Bucomazi formation (equivalent of the source rocks of the Tupi discovery, in deep-water of the Santos basin, Brazil) are readily recognized by the parallel internal configuration of their associated reflectors. The lower rift-type basin sediments correspond to the Lucula sandstones (potential reservoir-rock). The uppermost reflection terminations, against the substratum, correspond to the Toca lacustrine rift-type basin limestones.



The petrophysical characteristics of the rift-type basin generating and entrapment/migration subsystems are well depicted on the electrical logs of this well drilled by Gull Oil in the 60's. The positive resistivity/sonic interval in the Bucomazi, as in the Lucula shale interval, strongly suggests that the organic matter of these shales (lacustrine) reached maturation. In fact, as illustrated in the schematic diagram for interpretation), in the right part of the plate, when the organic matter of a potential source rocks is immature, the sonic is low and the resistivity is relatively flat. The potential reservoir-rocks of the rift-type basin petroleum system are either the lacustrine limestones (Toca formation, not illustrated on this well) or the Lucula sandstones (in yellow), as illustrated in the next plate.



These electrical logs illustrate the main reservoir-rock in the onshore Congo basin (Cabinda), i.e., the Lucula sandstones. As depicted, the Lucula formation, can be subdivided in three intervals: (i) The lower Lucula sandstones with a gross thickness of 257 m (67 m net) and an average porosity of 10%, (ii) A potential source-rock interval (lacustrine shales) and (iii) An upper reservoir interval with a gross thickness of 202 m (166 m net) with an average porosity of 16%. It is this petroleum system composed by a Bucomazi (Lucula source-rocks are secondary) generating petroleum subsystem and a Lucula (sandstone) or Toca entrapment-migration petroleum subsystems (lacustrine limestone in the top of the buried hills of the basement) that is the more likely equivalent to the Tupi petroleum systems that Gulf's geologists have put in evidence in the Congo basin in the 60's.

In conclusion:

(i) In Congo basin, en particularly in Cabinda, the equivalent of Tupi petroleum system is the Bucomazi / Toca, Bucomazi / Lucula and Bucomazi / Mayombe. These petroleum systems where tested in onshore Cabinda by Gulf Oil, in the 60's, but without seismic data. Their remaining petroleum potential is significant.

(ii) These petroleum systems are practically untested in the conventional offshore of Cabinda (continental crustal unit). In deep-water (volcanic crustal unity), they do not exist.

(iii) The lacustrine limestones found in Tupi discoveries can be considered as equivalent of the lacustrine limestone reservoirs of the Toca formation in Cabinda offshore.

(iv) The main generating petroleum subsystems of Tupi discoveries is a rift-type basin subsystem similar to the generating petroleum subsystem of onshore and conventional offshore of Cabinda (Bucomazi source-rocks).

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